FORAMINIFERAL EVIDENCE OF LATE QUATERNARY SEA LEVEL FLUCTUATIONS FROM THE WEST FLOWER GARDEN BANK

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ABSTRACT

The foraminiferal assemblages were analyzed in 8 piston cores and 22 surface samples from the West Flower Garden Bank in the northwest Gulf of Mexico in an attempt to accurately determine late Quaternary paleoclimatic and geologic events.

The faunas are subdivided into 3 distinct successive biofacies based on the planktonic foraminifers. The differences in the planktonic faunas that define these facies are directly related to climatic events. The lowermost *Turborotalia inflata* Facies is characterized by significant numbers of the cool water indicator *T. inflata* and an absence of the warm water *Globorotalia cultrata* group. The *Turborotalia crassaformis* Facies overlies the *T. inflata* Facies and is defined by small percentages of both *T. inflata* and the *Gl. cultrata* group. The uppermost *Gl. cultrata* Facies is characterized by significant numbers of the warm water *Gl. cultrata* group and the absence of *T. inflata*.

Several groups of benthonic foraminifers are also used to divide the faunas into environmental facies. A predominance of *Epistominella*, *Buliminella*, and *Nonionella* characterizes the Deltaic Marine Facies encountered in the clay section. The Inner

Continental Shelf Facies is characterized by a predominance of Rosalina, Elphidium, Cellanthus, and Ammonia. A predominance of Cassidulina and Cibicidoides is indicative of the Outer Continental Shelf Facies. The genus Amphistegina is known to flourish in reefal environments shallower than 40 m, and thereby is a valuable paleobathymetric indicator in the sediment on the West Flower Garden Bank.

The planktonic-benthonic ratio is used in conjunction with changes in these benthonic foraminifers to identify fluctuations in sea level. Examination of the total foraminiferal assemblage, both planktonic and benthonic forms, makes possible a direct correlation of late Quaternary fluctuations in sea level and paleoclimatic events.

The distribution of the sediment deposited during each of the planktonic facies allows an approximate determination of sea level at the boundaries of these facies. Prior to latest major rise in sea level, erosion of the bank exposed a previously buried deltaic clay unit. As sea level began to rise over the flanks of the West Flower Garden Bank, the sediment of the T. inflata Facies was deposited unconformably above this deltaic clay. At the top of this facies sea level stood at -73 m. At the boundary between the T. crassaformis Facies and the overlying Gl. cultrata Facies, sea level had reached -53 m. The boundary between these two facies is believed to correspond to the Pleistocene-Holocene boundary. Increased warming and glacial melting during the Holocene brought sea level to its present position. These events display excellent correlation with those inferred from a core taken on nearby Phleger Bank.

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INTRODUCTION

The unique foraminiferal faunas present in the sediment on and around the West Flower Garden Bank provide an ideal opportunity for the detailed study of late Quaternary fluctuations in sea level. The compositional changes in these faunas can be directly related to late Quaternary geologic, oceanographic, and paleoclimatic events through the use of paleoecological techniques, biostratigraphy and radiocarbon dating.

The outer continental shelf and upper continental slope in the northern Gulf of Mexico are dotted with numerous submarine banks generally thought to be the surface expression of salt diapirs. The tops of many of these banks are covered with coarse carbonate sediment. The West Flower Garden Bank is one of these structures, and is located about 100 miles south southeast of Galveston, Texas, at longitude 93°49.0' west and latitude 27°52.6' north (Figs. 1 and 2). The main pinnacle rises to within 19 m of the sea surface and displays 116 m of relief. A secondary pinnacle located west of the main pinnacle, rises to within 45 m of the sea surface. Along with the East Flower Garden Bank, it forms the northern limit of known reef coral growth in the Gulf of Mexico.

Due to the 116 m of relief, there is a marked change in the

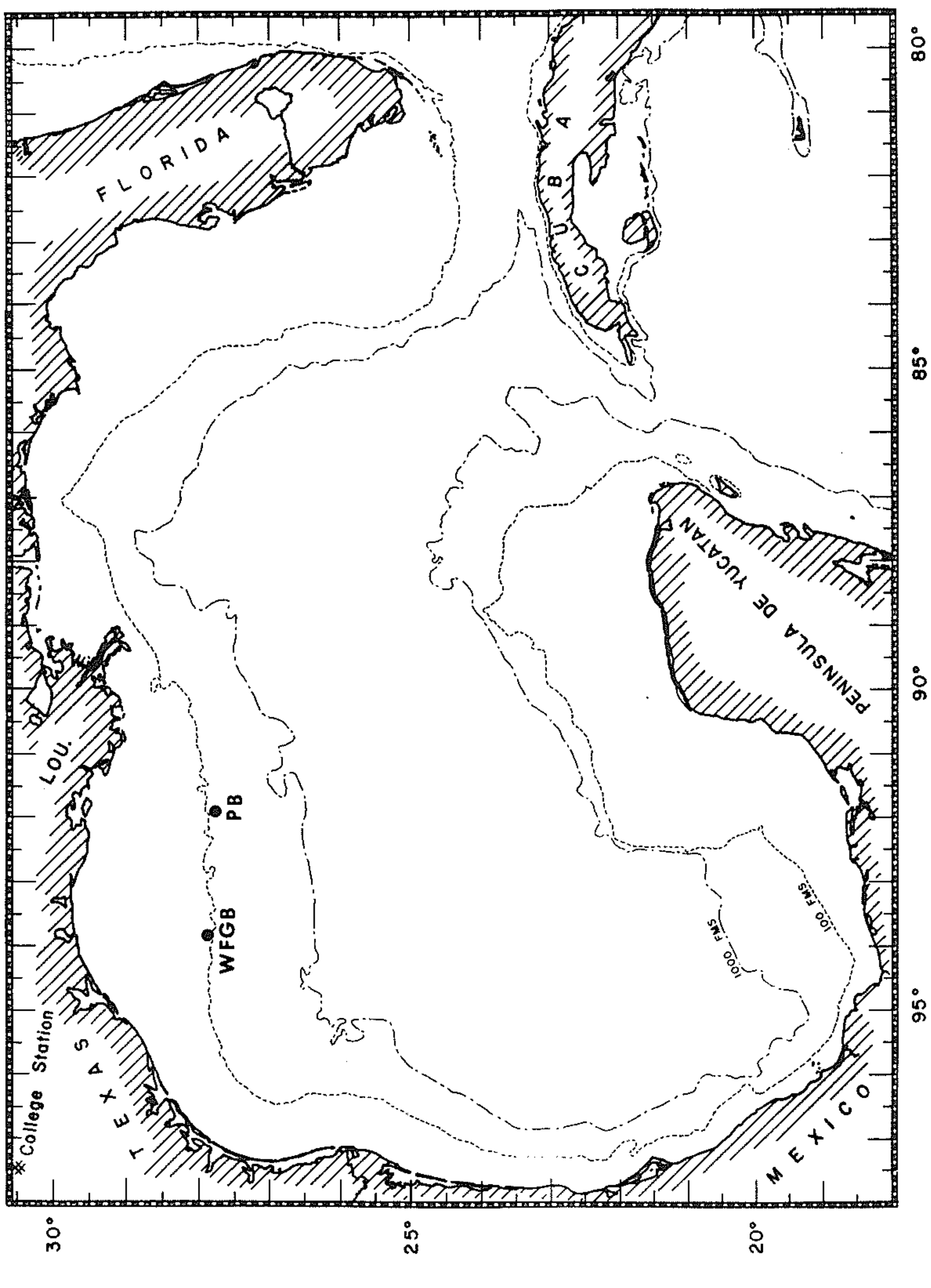


Fig. 1-Location of West Flower Garden Bank (WFGB) and Phleger Bank (PB).

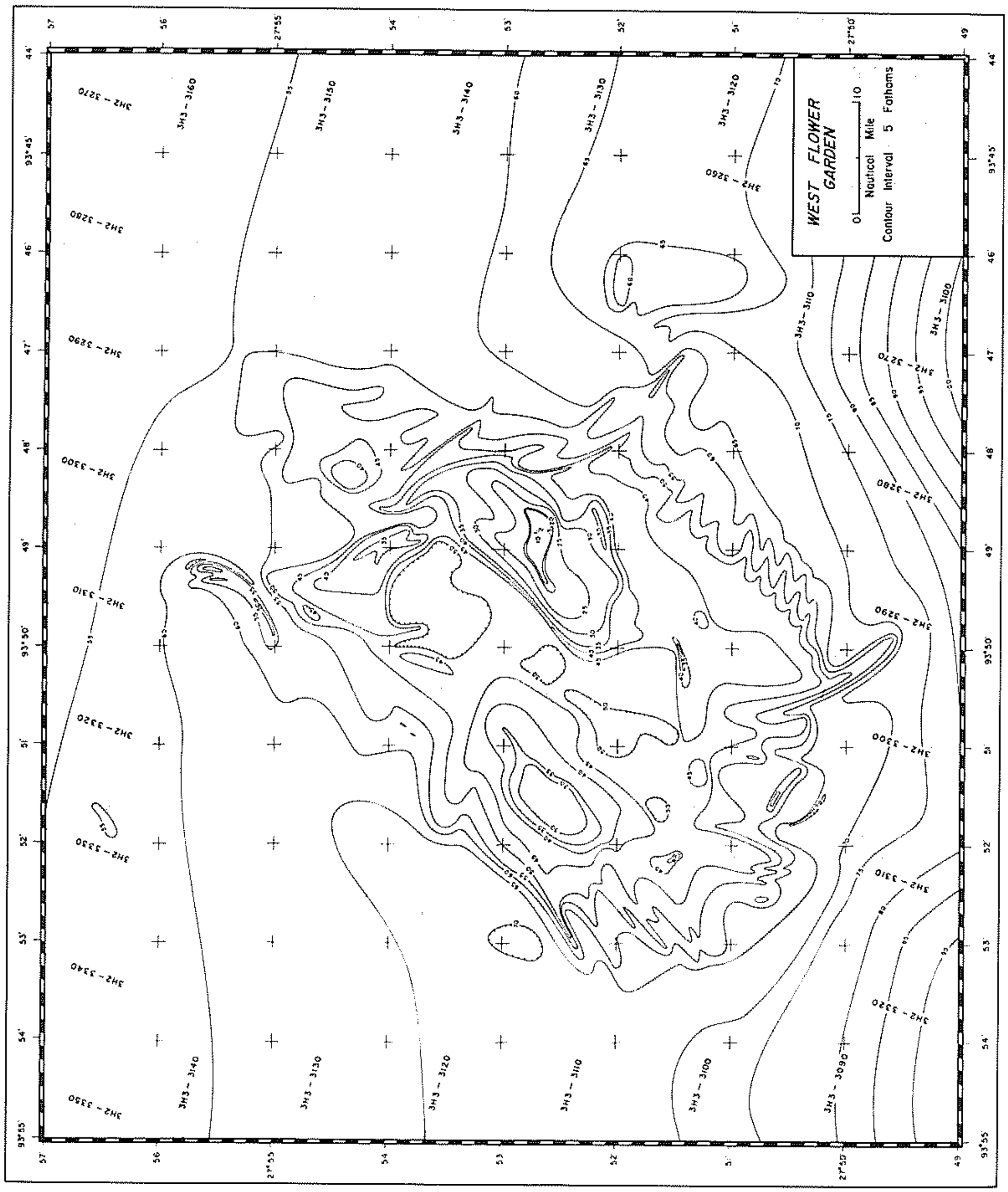


Fig. 2-Bathymetric chart of the West Flower Garden Bank
(after Edwards, 1971).

benthonic foraminifers at different bathymetric levels on the West Flower Garden Bank. These benthonic forms are excellent environmental indicators. As the bank is presently surrounded by 101-128 m (50-70 fms) of water, the remains of plantonic foraminifers are also present in the sediment on the flanks of the structure. The living planktonic foraminifers are sensitive to changes in temperature and salinity and, as buried sediment, reflect paleoclimatic changes. The ratio of planktonic to benthonic foraminifers increases in the direction of deeper water. Variations in this ratio in vertical sequences can be used to aid in identifying fluctuations in sea level. These planktonic organisms can also be utilized to identify the Pleistocene-Holocene boundary.

The foraminiferal faunas from the bank lend themselves to direct correlation between paleoecologic, biostratigraphic, and paleoclimatic events. The abundant calcium carbonate in the cores allows radiocarbon dating of any small interval of the core, providing an accurate chronology of each sequence.

PREVIOUS WORK

Sea Level Fluctuations

In the past, determination of late Quaternary sea levels has been based predominantly on such morphologic features as the depths of submerged bank crests, submarine terraces and submerged shoreline features. Sea level fluctuations reflected in the shelf sediments of the northern Gulf of Mexico have been described by several authors (Fisk and McFarlan, 1955; Parker and Curray, 1956; Curray, 1960; McFarlan, 1961; Nelson and Bray, 1970, Ballard and Uchupi, 1970).

Edwards (1971) identified five late Quaternary sea levels based on submerged terraces and erosional unconformities present on the West Flower Garden Bank. He placed these sea levels at -51 m, -73 to -83 m, -89 to -90 m, -121 to -134 m, and deeper than -182 m.

Poag (in press) has reviewed the various studies of late Quaternary sea levels in the Gulf of Mexico. He credits the large number of sea levels recognized in the literature (26) to the complexity of climatic fluctuations as indicated from studies of deep-sea cores and to regional and local tectonic movements. It is clear that correlation of late Quaternary sea levels on a regional scale is impossible without adequate radiometric dates and stratigraphic data.

Bank Faunas

The tops of many of the submarine banks in the northern Gulf of Mexico are covered with coarse carbonate sediment. The foraminiferal faunas that partially compose this sediment have been briefly described by several authors (Lowman, 1949; Phleger, 1951; Bandy, 1956; Ludwick and Walton, 1957; Loep, 1965). Recently Poag and Sweet (1972) and Poag (1972) have published more detailed descriptions of the foraminiferal assemblages from 9 of these banks. The latter 2 reports indicate that the primary components of these bank assemblages are not characteristic of the level shelf in the north-central and north-west Gulf of Mexico. Instead, they show affinities to the shallow reefal communities in Florida and throughout the West Indian region.

One species common to the West Indian fauna and predominant on the banks is *Amphistegina gibbosa*. However, this species is living in abundance only on banks whose crests are shallower than 40 meters. The presence of high percentages of dead *A. gibbosa* on banks whose crests are deeper than 40 meters suggests that this species flourished during a lower stand of sea level. It appears that the reefal foraminiferal assemblages on many banks are relict, having been produced during a lower stand of sea level. These conclusions are supported by the work of Seiglie (1968), who also found discordant depth distributions among living and relict *Amphistegina* assemblages. Other foraminifers characteristic of the West Indian fauna and found on the West Flower Garden Bank include *Homotrema rubra* and *Peneroplis proteus* (Poag, 1972).

It appears from the distribution of living *Amphistegina gibbosa* that the fluctuations in the relative abundance of this species in core samples can be used to identify changes in sea level relative to the bank. From a core taken on Phleger Bank (Fig. 1), Poag (1972) has related fluctuations in the abundance of *A. gibbosa* directly to changes in the planktonic assemblages (Fig. 3). These vertical changes in the planktonic assemblage show excellent correlation with those reported from the south-western Gulf of Mexico (Kennet and Huddlestun, 1972; Sidner and Poag, 1972; Beard, in press).

The foraminiferal faunas present on the submarine banks in the northern Gulf of Mexico also contain representatives of the level bottom fauna present on the surrounding shelf and slope. The distribution of benthonic foraminifers on the shelf and slope in this region have been studied by several workers including: Lowman (1949); Phleger (1951), Phleger and Parker (1951); Parker (1954); Bandy (1956); Lankford (1959); Phleger (1960); Loep (1965); Tipsword et al. (1966).

Grimsdale and van Morkhoven (1955) have demonstrated a relationship between the ratio of planktonic to benthonic foraminifers and water depth. Though their study did not provide an accurate quantitative method of determining paleobathymetry, it did point out the general pattern of increasing planktonic-benthonic

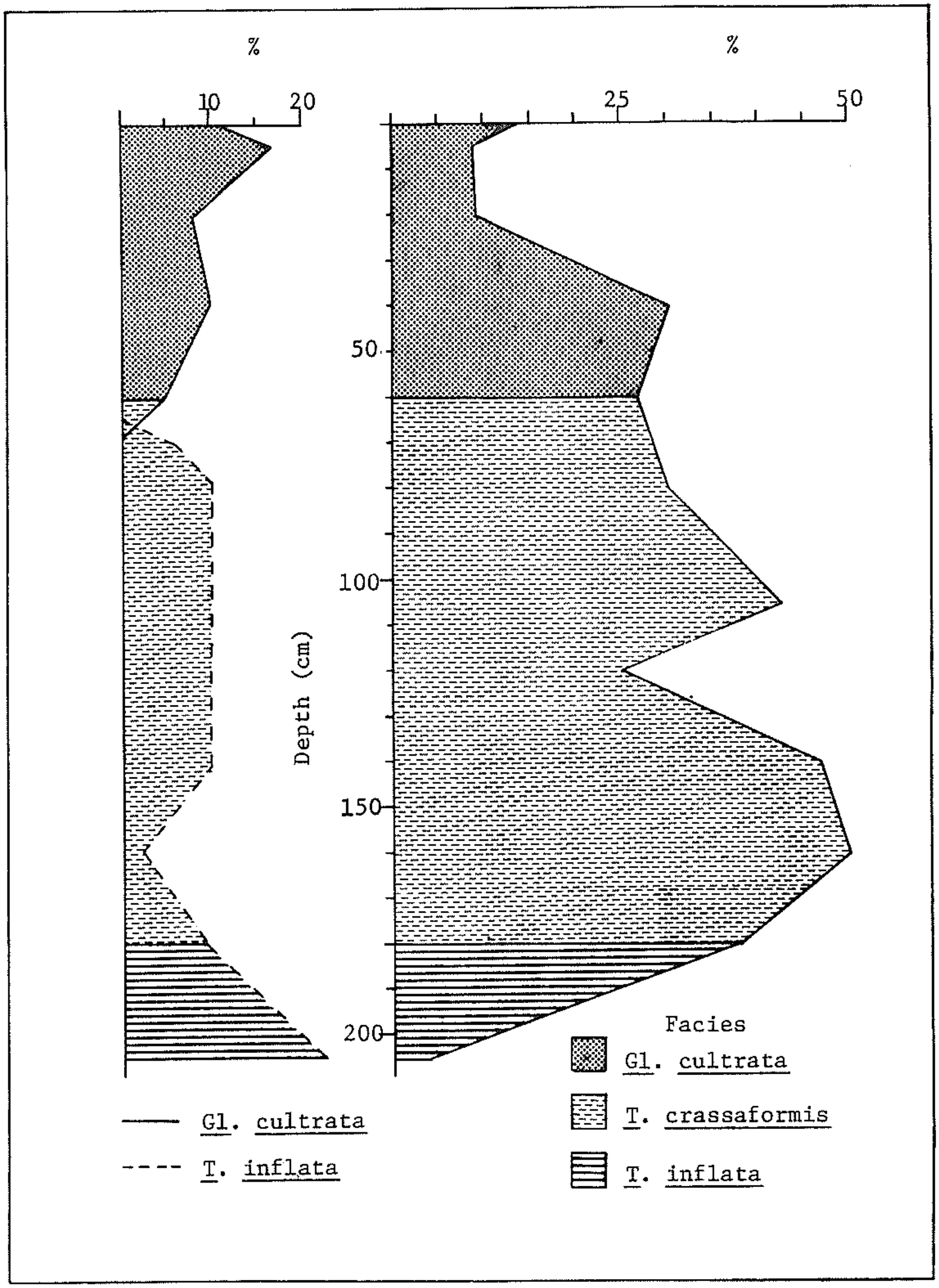


Fig. 3-Planktonic facies as defined by the relative abundance of Gl. cultrata and T. inflata (left). The vertical fluctuations in the relative abundance of Amphistegina (right) are from the same Phleger Bank Core (after Poag, 1972).

ratios with increasing water depth across the shelf and slope. Whether this general pattern is entirely a result of the greater number of planktonic foraminifers present in deeper water columns or a reflection of changing sedimentation rates (Lankford, 1966) is not known.

West Flower Garden Bank

Edwards (1971) described the reef building organisms and surface sedimentary facies which occur in nearly concentric bands around the West Flower Garden Bank (Fig. 4). The shallowest sediment facies described by Edwards (1971) is the *Diploria-Montastrea-Porites* Facies, which ranges from the top of the bank (-19 m) to approximately -50 m. This zone of living corals forms the main pinnacle of the bank. Below this facies on the main pinnacle is the Coral Debris Facies, which forms a transition between the *Diploria-Montastrea-Porites* Facies and the deeper *Gypsina-Lithothamnium* Facies. This latter facies ranges in depth from approximately 46-73 m to 82 m and is present on both pinnacles of the bank. This facies is characterized by algal-foraminiferal nodules composed of the foraminifer *Gypsina plana* and several types of crustose coralline algae including *Lithothamnium*. The fourth main facies described by Edwards (1971) is the *Amphistegina* Facies, which ranges in depth from -73 to -100 m. Within this facies Edwards found that the foraminifer *Amphistegina* comprises up to 25% of the total sediment (by point count). The fifth major

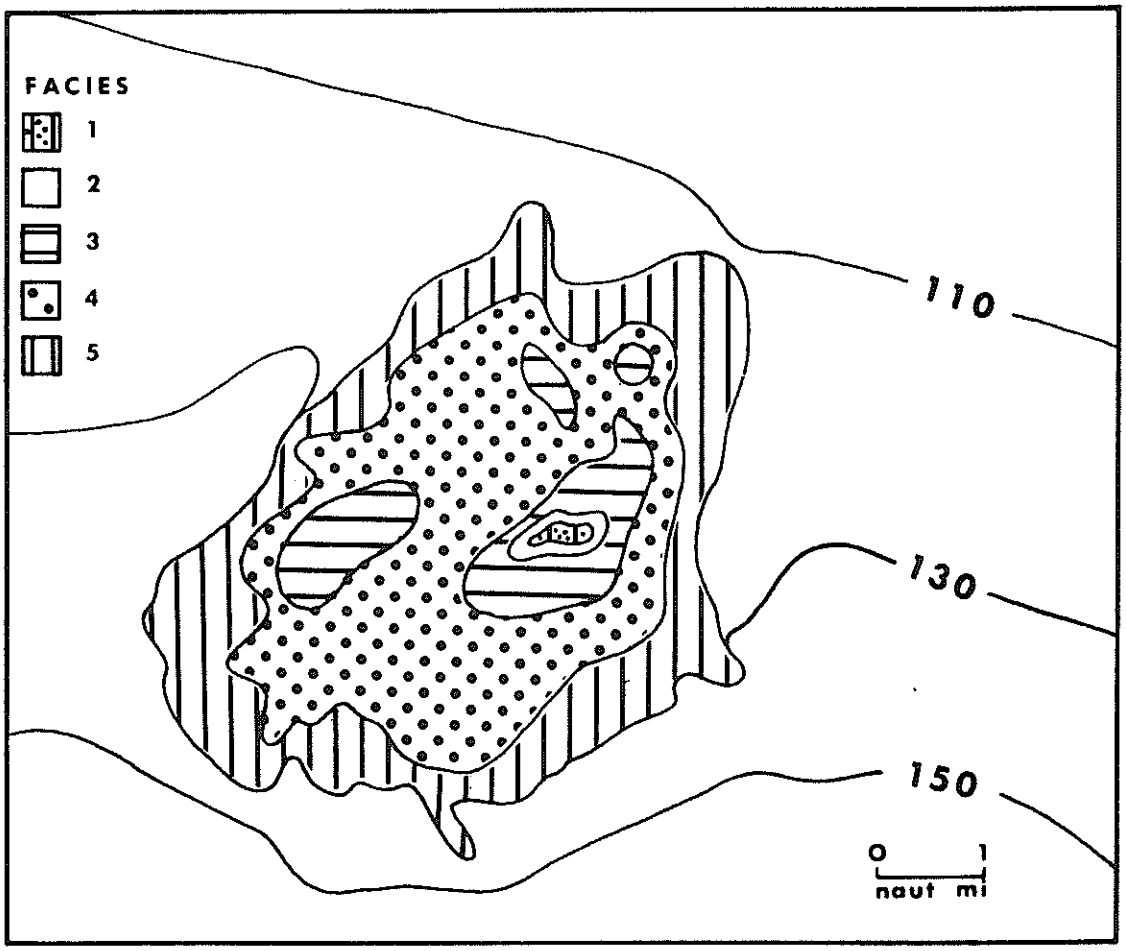


Fig. 4-Sediment facies map of the West Flower Garden Bank (modified from Edwards, 1971, from Poag, 1972)

Facies 1: Diploria-Montastrea-Porites
Facies 2: Coral debris
Facies 3: Gypsina-Lithothamnium
Facies 4: Amphistegina
Facies 5: Quartz-Planktonic foraminifers

facies is the Quartz-Planktonic Foraminifera Facies, which has a shallow limit of -91 m. This facies forms a transition between the predominantly carbonate sediment on the bank and the terriginous sediment characteristic of the surrounding shelf. The relative abundance of planktonic foraminifers also increases with water depth within this facies.

Rezak and Bryant (in press) recently conducted a survey of the West Flower Garden Bank using a submersible. Their survey confirmed Edwards' pattern of sediment facies outlined above.

PROCEDURES

The surface samples and cores examined in this study were collected on cruise 70-A-13 of the R/V ALAMINOS. The surface samples were taken with a van Veen grab sampler and the cores with a piston corer containing a plastic liner. In order to prevent bending the core pipe in the coarse carbonate material on the shallower portions of the bank, only one 6.1 m (20 ft) section of 7 cm (2.75 in. inside diameter) pipe was used.

The cores were split longitudinally on a band saw and sampled at approximately 40 cm intervals. Exceptions to this sampling interval were based on lithologic changes encountered and the total length of each core. Each sample consisted of approximately 25 cc of sediment. When algal nodules were encountered, the samples were larger.

The preparation of the core and surface samples was identical. The samples were boiled in Calgon, a dispersive agent, and washed through a 200 mesh (75 μ) screen. The retained fractions were then oven-dried. The dried residues were split with a Soiltest microsplitter to obtain a representative fraction. The split samples were then examined under a binocular stereomicroscope.

A minimum of 300 specimens was counted from each of the 22 surface samples in an attempt to determine variations in the planktonic-benthonic ratio at various levels of the bank. The relative percentage of *Amphistegina* was also noted in these counts.

A minimum of 300 specimens, both benthonic and planktonic foraminifers, was picked from each core sample and placed on a 60-hole micropaleontological slide. These specimens were then identified and the generic composition determined. The presence of certain species believed to be stratigraphic or climatic indicators was also noted.

Once the faunal compositions were determined, samples were taken at critical levels for radiocarbon age determination. These samples were taken from various coarse carbonate facies and consisted mainly of one or more algal nodules.

The photomicrographs of the foraminifers displayed in Appendix E were taken on a Jelco JSMU-3 scanning electron microscope using Polaroid Type P/N 55 film. These photographs were reprinted on Kodak Kodabromide F-5 paper to increase their contrast. The prints were then mounted on black posterboard and photographed using Kodak Ektapan film. The negatives were printed on Kodak Kodabromide A-3 paper.

OBSERVATIONS

Planktonic-Benthonic Foraminiferal Ratio

The validity of variations in the planktonic-benthonic ratio in surface sediments was established for use as an indication of changes in sea level. Samples obtained with a van Veen grab sampler were used in this determination due to the necessity of obtaining the true top of the sediment column (Fig. 5; Table A-1). Tops of piston cores often do not represent the surface sediments due to mixing or complete loss of the upper few centimeters of sediment.

The distribution pattern indicated by these planktonic-benthonic ratios is illustrated in Figure 6. These ratios appear to be directly proportional to the water depth at the various levels of the bank. The ratios are low on the crests of the bank and increase with the water depth down the flanks of the structure.

It has also been suggested (Lankford, 1966) that an increase in the planktonic-benthonic ratio is a function of decreasing rates of clastic sedimentation and decreasing benthonic productivity with increasing water depth. This explanation could be used to justify the rapid lateral decrease in the ratios that occurs toward the top of the bank. The rates of calcium carbonate sedimentation increase toward the crests. This increase in sedimentation, much of which is the result of the deposition of calcareous benthonic foraminiferal tests, would decrease the

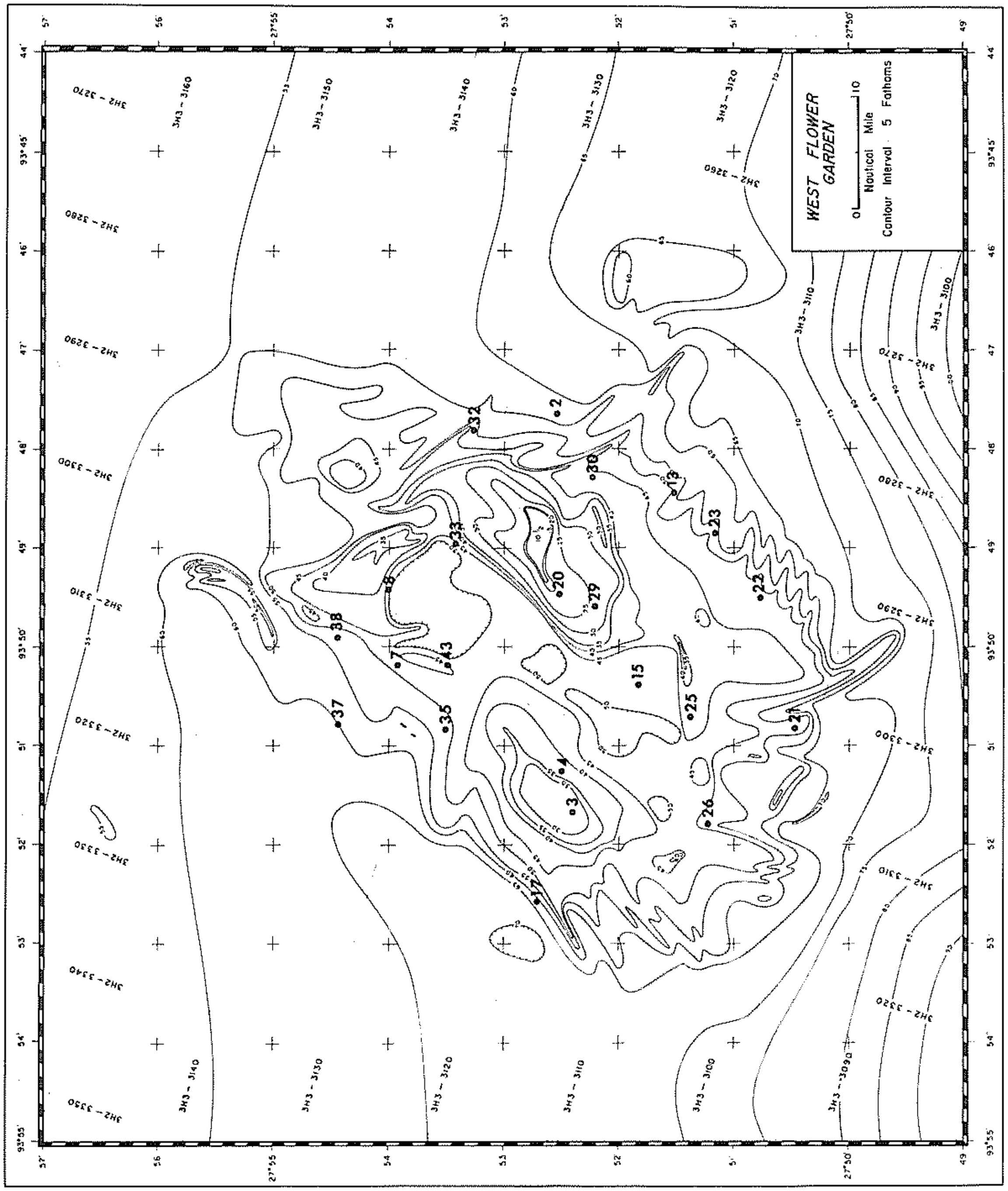


Fig. 5-Location of surface samples.

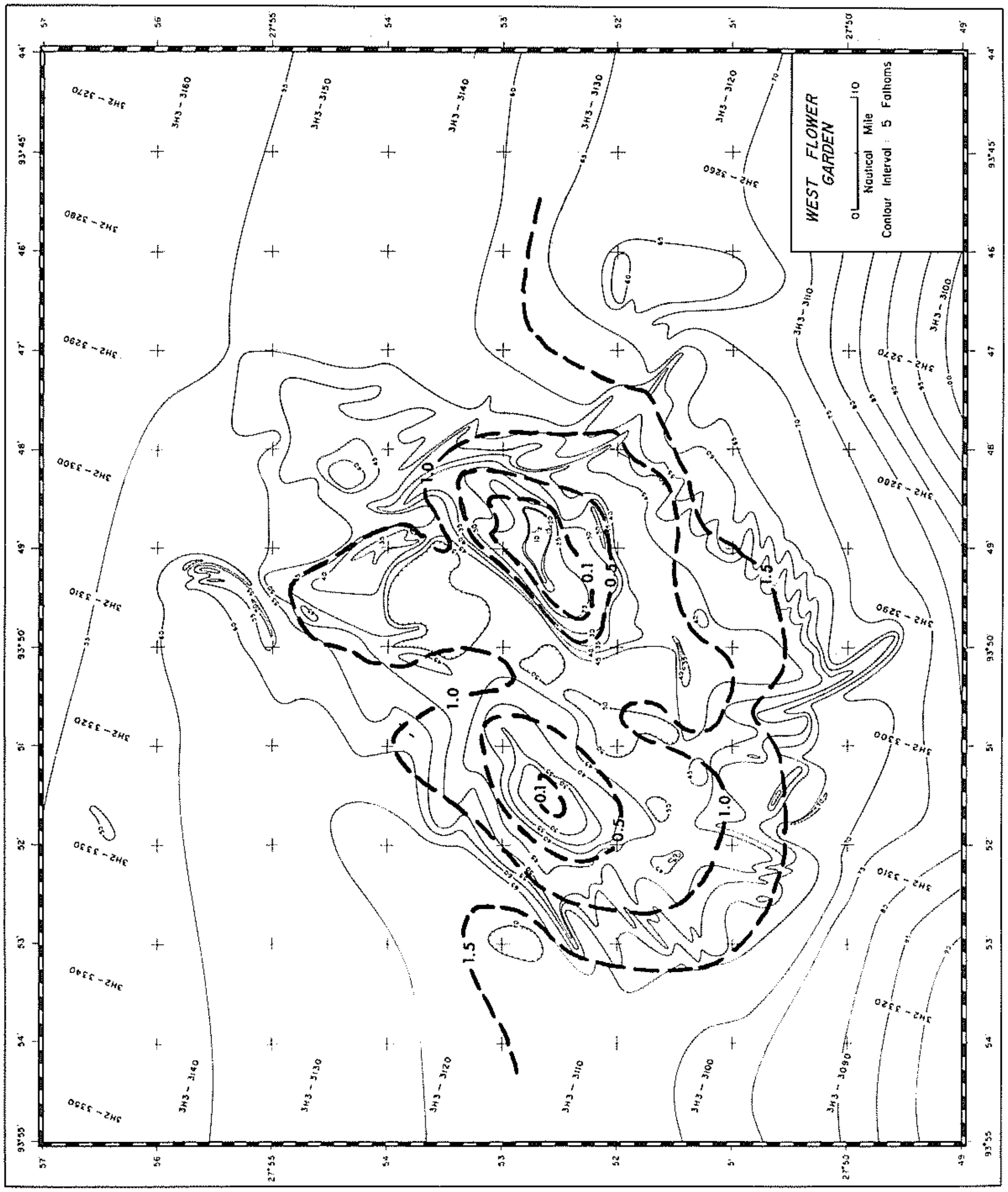


Fig. 6-Contoured planktonic-benthonic ratios based on the 22 surface samples.

planktonic-benthonic foraminiferal ratio. It is also possible that winnowing of the less dense planktonic tests from the crests of the bank could cause a decrease in the planktonic-benthonic ratio.

It appears that the ratio of planktonic to benthonic foraminifers is not solely dependent on a single factor. Instead, it is the result of a combination of controls acting within a given sedimentary regime. For this reason, identification of depositional environments cannot be based on this measure alone. If used with the composition of the benthonic foraminiferal fauna and planktonic climatic indicators, however, the planktonic-benthonic ratio can be a valuable tool in environmental interpretations.

Planktonic Foraminiferal Facies

The foraminiferal assemblages from the cores (Fig. 7) were examined in an attempt to relate paleoclimates directly to fluctuations in sea level. Since planktonic foraminifers are sensitive to changes in the temperature of the surface waters, they can be used as climatic indicators.

The *Globorotalia cultrata* group, which consists of *Gl. cultrata*, *Gl. tumida*, *Gl. fimbriata*, and *Gl. ungulata*, has been extensively used as an indicator of warm tropical waters (Phleger, 1951; Ewing, Ericson, and Heezen, 1958). This group is common in the Gulf of Mexico today. The temperate water indicator

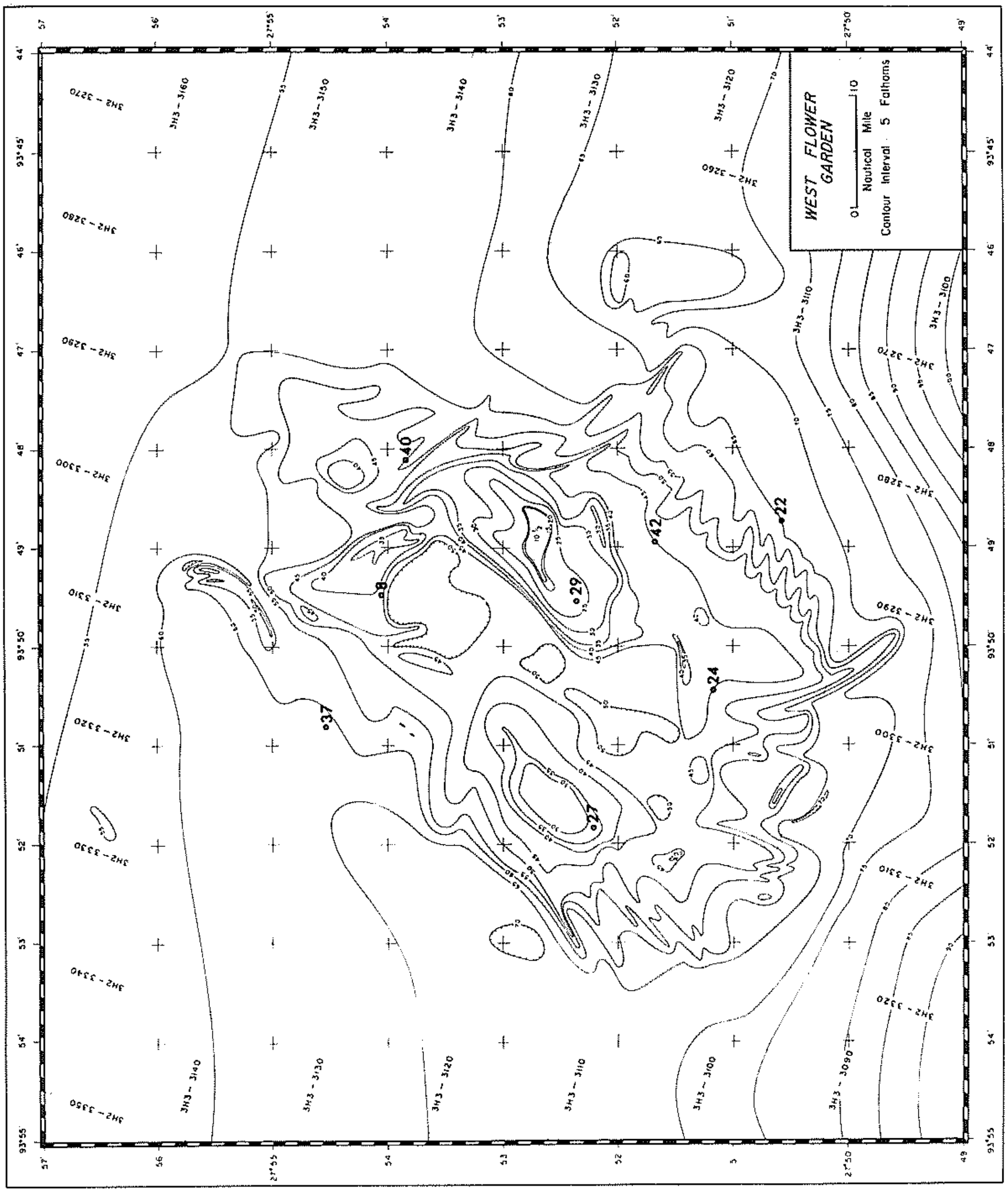


Fig. 7-Location of core sites.

Turborotalia inflata is rare in the surface waters of modern Gulf of Mexico; but has been obtained in plankton tows (J. I. Jones, personal communication to C. W. Poag, 1972).

Fluctuations in relative abundance of these warm-cool indicators throughout the late Quaternary are very consistent in cores from the western Gulf of Mexico (Kennet and Huddlestun, 1972; Beard, in press). Sidner and Poag (1972) placed the planktonic foraminifers from 12 cores, taken in the southwest Gulf of Mexico, into three distinct, consecutive biofacies (Fig. 8).

The oldest planktonic facies encountered in the study area is the *Turborotalia inflata* Facies. This facies represents a period when the surface waters were cooler than those in the western Gulf of Mexico today. The *Turborotalia crassaformis* Facies forms a transition between the cool *T. inflata* Facies and the warmer, overlying *Globorotalia cultrata* Facies. This Facies is characterized by a moderate increase in *T. crassaformis* and low percentages of *T. inflata* and the *Gl. cultrata* group. The *Gl.* cultrata Facies forms the upper layer in all undisturbed cores containing modern pelagic sediment. It is characterized by the warm water indicators of the *Gl. cultrata* group and an absence of *T. inflata*.

Bathymetric Interpretation of Benthonic Foraminiferal Facies

The benthonic foraminifers are good bathymetric indicators and, thus, also reflect fluctuations in sea level. Phleger

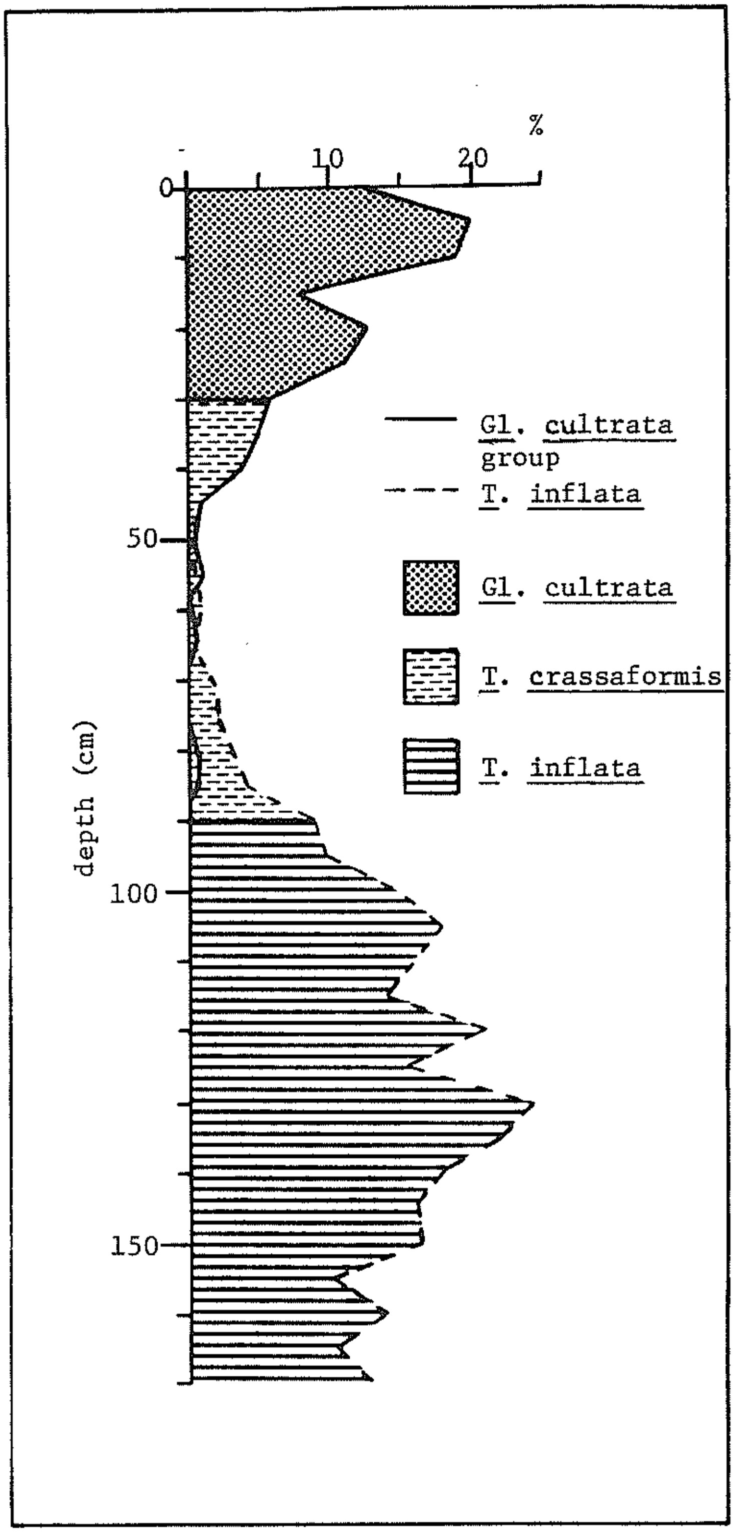


Fig. 8-Planktonic facies based on the relative percentages of Gl. cultrata and T. inflata.

(1960a, b) outlined the distribution of modern benthonic foraminifers in the northwest Gulf of Mexico. In these reports he listed the groups of genera that are characteristic of given environments. If used in the same geographical area, these genera can also serve to identify paleoenvironments. The paleoenvironments and characteristic genera recognized in this study are indicated below.

<u>Deltaic Marine Facies</u>

<u>Nonionella</u>, <u>Buliminella</u>, <u>Epistominella</u>, and <u>Brizalina</u>

<u>Inner Continental Shelf Facies</u>

<u>Buliminella</u>, <u>Rosalina</u>, <u>Elphidium</u>, <u>Ammonia</u>, and <u>Cellanthus</u>

<u>Outer Continental Shelf Facies</u>

<u>Bigenerina</u>, <u>Cassidulina</u>, <u>Cibicidoides</u>, <u>Euuvigerina</u>, and <u>Fursenkoina</u>

<u>Upper Continental Slope Facies</u>

<u>Brizalina</u>, <u>Bulimina</u>, <u>Cassidulina</u>, <u>Pullenia</u>, and <u>Euuvigerina</u>

If eustatic fluctuations in sea level are directly related to climatic events (glacial advance and retreat), then a lowering of sea level would be accompanied in the Gulf of Mexico by an influx of cooler-water planktonics. As the planktonic-benthonic ratio decreases, an increase in shallow water benthonics, a decrease in warm-water plankters, and an increase in the cooler-water planktonics would be expected in the sediments on and around the West Flower Garden Bank.

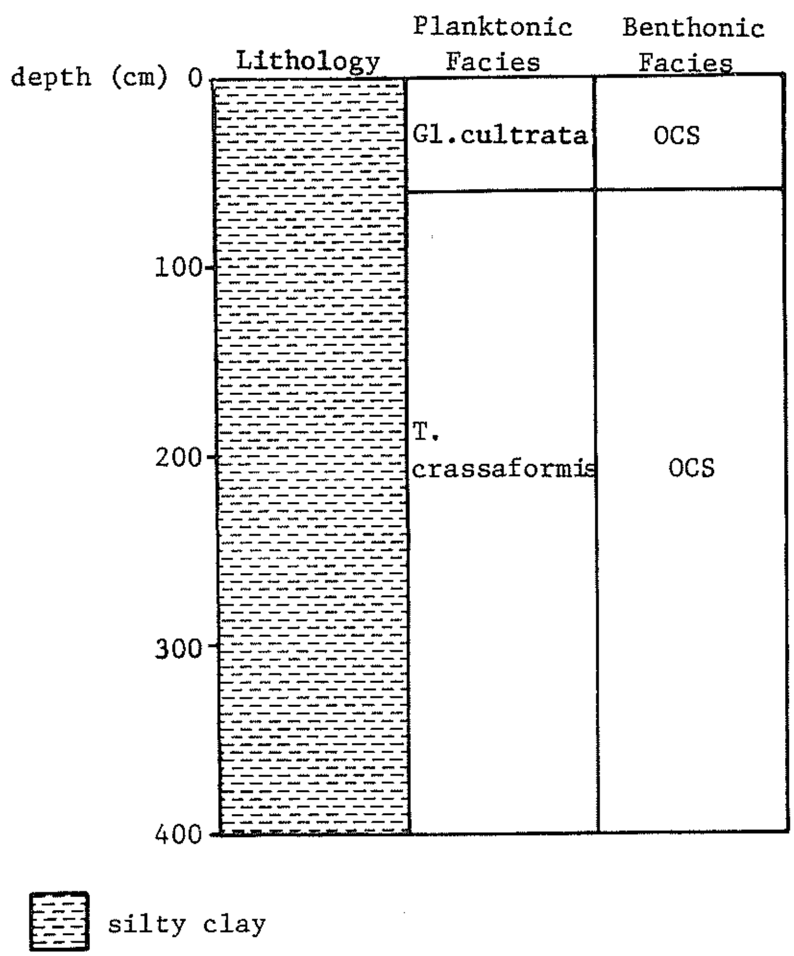
In order to assist in correlating the events in each core, the writer attempted to discern species whose stratigraphic ranges are limited. Only one benthonic foraminifer can be used as a stratigraphic indicator within this study area. Elphidium sagrum (Appendix E, Plate 4) is absent in the Gl. cultrata Facies of the West Flower Garden Bank cores. Bock (1971) reported this species living in Florida Bay.

Analysis of Core Faunas

Core 37 (Appendix B; Table C-1; Fig. 9)

The changes in the planktonic-benthonic ratio in Core 37 correlate well with the variations in the planktonic climatic indicators (Fig. D-1). The increase in the planktonic-benthonic ratio between 80 and 40 cm is accompanied by the first stratigraphic occurrence of members of the Gl. cultrata group (Fig. 7).

The benthonic foraminifers also show good correlation with variations in the planktonic-benthonic ratio. The low planktonic-benthonic ratios in the samples between 400 and 80 cm are to be expected considering the predominance of benthonic foraminifers characteristic of the inner continental shelf (Fig. D-2). The change from an inner continental shelf fauna to an outer continental shelf fauna between 80 and 40 cm is accompanied by an increase in the planktonic-benthonic ratio (Fig. D-3).



silty clay

OCS- outer continental shelf

ICS- inner continental shelf

Fig. 9-The planktonic facies, benthonic facies, and lithology of Core 37.

The genera characteristic of a deltaic marine environment follow much the same stratigraphic pattern as the genera representative of an inner continental shelf environment (Fig. D-4). Their presence in the abundances encountered suggests a fresh water influence on the inner continental shelf environment represented by the 400 to 60 cm interval of Core 37.

Between 400 and 360 cm there is a slight increase in the inner continental shelf and deltaic marine genera. There is a corresponding small decrease in the percentage of *Cibicidoides* and the planktonic-benthonic ratio. These trends suggest a minor fluctuation in sea level within the *Turborotalia crassaformis* Facies.

Core 40 (Appendix B; Table C-2; Fig. 10)

Between 440 and 273 cm the planktonic-benthonic ratio generally decreases from 0.12 to 0.02 (Fig. D-5). The outer continental shelf genera are also present in greater abundances within the 440-273 cm interval than in the overlying 273-20 cm interval of Core 40 (Fig. 10). However, this interval from 440 to 273 cm is still interpreted as having been deposited in inner continental shelf water depths, based on the relative abundances of *Rosalina* (Fig. D-6), *Elphidium*, and especially *Amphistegina*. *Amphistegina* is the predominant benthonic genus between 440 and 273 cm but its numbers diminish sharply between 273 and 237 cm (Fig. D-8).

Between 200 and 20 cm, small numbers of *T. inflata* and *Gl. cultrata* occur together. This mixture is often encountered within

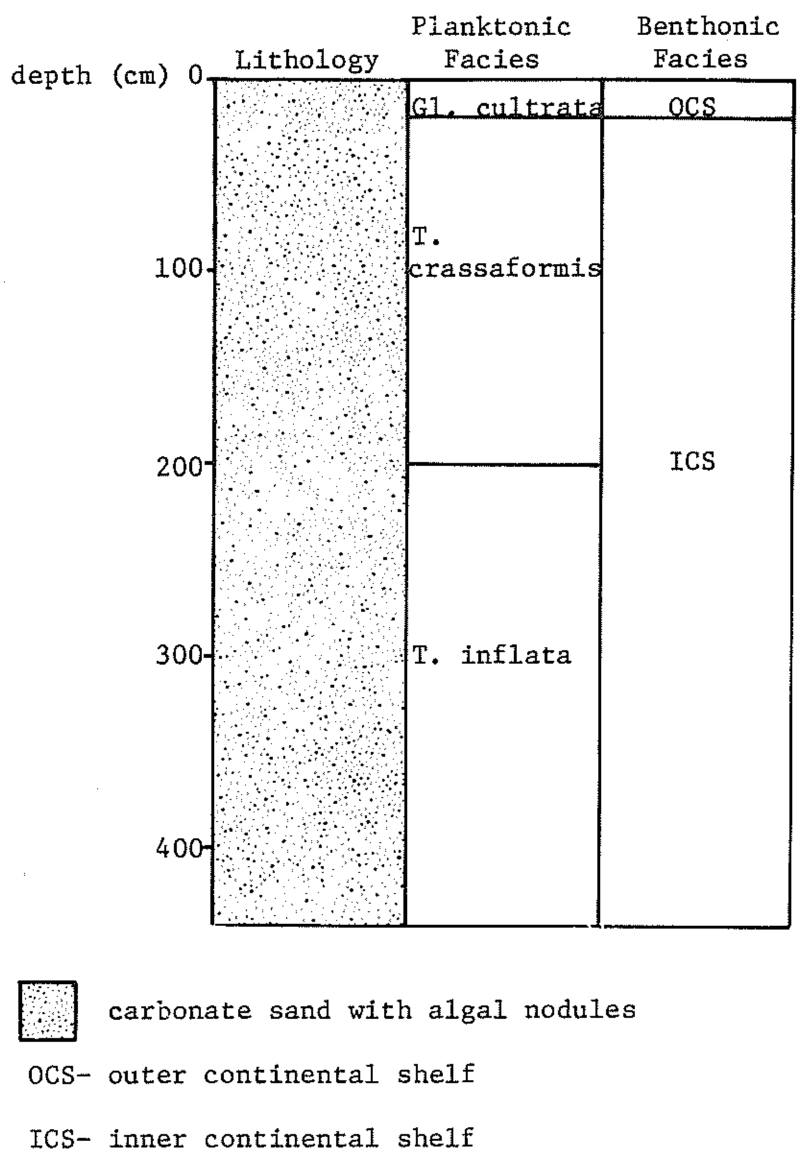


Fig. 10-The planktonic facies, benthonic facies and lithology of Core 40.

the *T. crassaformis* Facies.

The top sample of Core 40 contains representatives of the *Gl. cultrata* group. However, the planktonic-benthonic ratio in this sample is 0.32, lower than would be expected at a depth of -91 m. It appears that the top sample may not represent the true top of the sediment column.

Core 8 (Appendix B; Table C-3; Fig. 11)

The 433 cm sample contained only 46 specimens, many of which showed signs of abrasion, glauconitization, and dissolution. In this sample *Ammonia beccarii* makes up 43.5% of the total assemblage (Fig. D-9). Both *Buliminella* and *Epistominella* are absent at this level in the core. Both of these forms are abundant at 400 cm in Core 8. As *Buliminella* and *Epistominella* have fragile tests it seems likely that their absence at 433 cm is due to dissolution.

A lower stand of sea level during the deposition of the *T. inflata* Facies (393-130 cm) is indicated by the presence of inner continental shelf benthonic genera and a low planktonic-benthonic ratio (Fig. 11). The benthonic genera (Fig. D-11) and planktonic-benthonic ratio do not change significantly from the *T. inflata* Facies to the *T. crassaformis* Facies (Fig. D-10). However, with the influx of the *Globorotalia cultrata* group (60 cm) there is a concomitant increase in the outer continental shelf benthonic genera (Fig. D-12) and the planktonic-benthonic ratio.

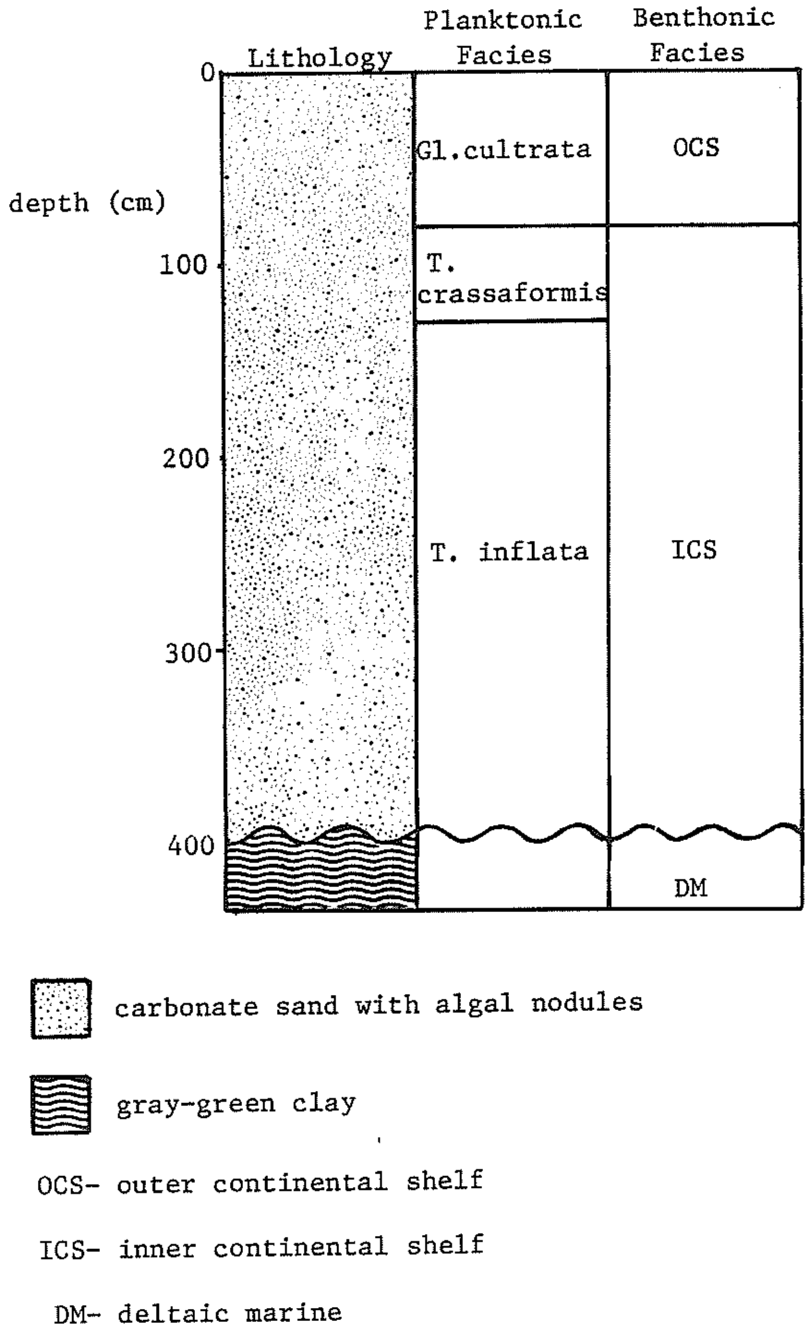


Fig. 11-The planktonic facies, benthonic facies and lithology of Core 8.

Amphistegina is present in each sample from the coarse carbonate section of Core 8 (Fig. D-13). However, it is predominant only in the 200 and 60 cm samples. The predominance of *Amphistegina* in these samples would seem to indicate water depths shallower than 40 m. However, in the 60 cm sample the influx of *Amphistegina* is accompanied by an increase in the planktonic-benthonic ratio and the relative abundance of the outer continental shelf benthonic genera. Other reefal genera present in the coarse carbonate section of Core 8 include *Homotrema*, *Gypsina*, *Peneroplis*, and *Archaias*. The fact that *Amphistegina* and *Archaias* are present in the 400 cm sample near the top of the clay section can be attributed to a mixing of sediment across the unconformity by burrowing organisms.

Core 29 (Appendix B; Table C-4)

The planktonic faunas at 40 and 0 cm in core 29 can be placed in the *Gl. cultrata* Facies. This is consistent with the high planktonic-benthonic ratio and the abundance of outer continental shelf genera present throughout the length of the core.

Members of the genera *Epistominella* and *Ammonia*, which are the predominant forms present in the basal clay section of core 8, are also present in the 40 cm sample of core 29. The existence of a hard clay unit just below 40 cm may explain the poor sediment recovery at this core site. The presence of *Ammonia* and *Epistominella* at 40 cm (Core 29) may represent reworking from this underlying unit. The 40 cm sample also contains abundant glauconite and well rounded quartz grains.

Amphistegina is rare (0.6%) in the 40 cm sample of the core, but becomes the predominant component of the assemblage in the 0 cm sample.

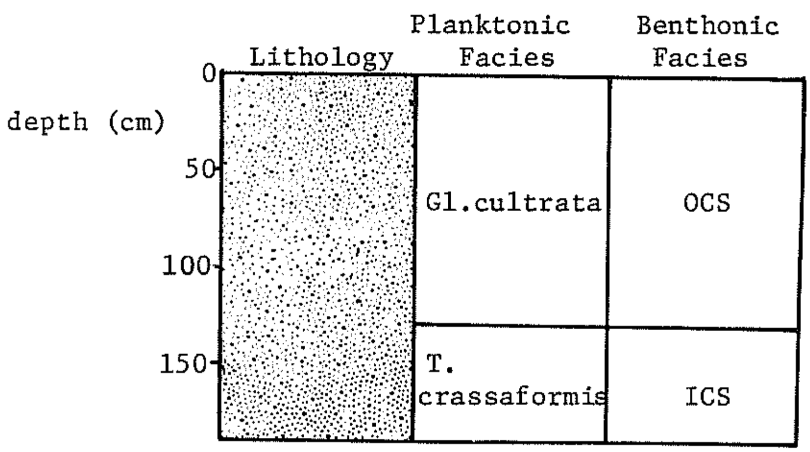
Core 27 (Appendix B; Table C-4; Fig. 12)

Representatives of the Gl. cultrata group are present in each of the 5 samples from Core 27. However, the presence of moderate abundances of T. crassaformis in the 190 and 150 cm samples indicates that this lower section of the core represents the upper portion of the T. crassaformis Facies (Fig. 12). The planktonic-benthonic ratio generally increases within the Gl. cultrata Facies reaching a maximum of 1.07 at the top of the core (Fig. D-16). The outer continental shelf genus Cassidulina is absent within the T. crassaformis Facies but is present (2.7-4.9%) within the Gl. cultrata Facies (Fig. D-14).

The inner continental shelf genera display no distinct patterns of variation with depth in Core 27. Elphidium and Cellanthus are rare in the core while Rosalina is a major component of the benthonic fauna.

Within the interval from 190 to 150 cm, Amphistegina varies between 11.1% and 15.6%. The relative abundance of Amphistegina decreases to 4.4% at the top of Core 27 (Fig. D-15).

The small influx of Ammonia and Epistominella in the 190 cm



carbonate sand with algal nodules

OCS- outer continental shelf

ICS- inner continental shelf

Fig. 12-The planktonic facies, benthonic facies and lithology of Core 27.

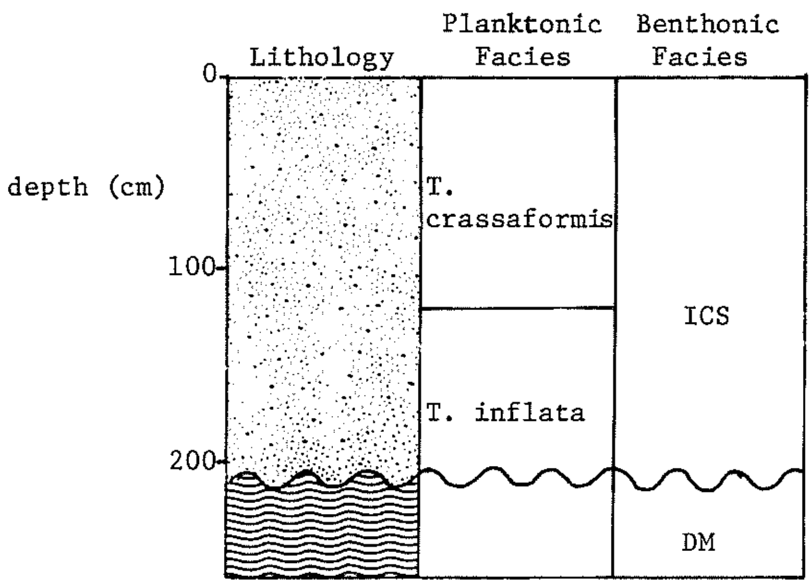
sample can be attributed to reworking from an underlying clay unit. Thus, the presence of a shallow clay unit may be the cause of the poor sediment recovery in both Core 27 and Core 29.

Core 42 (Appendix B; Table C-5; Fig. 13)

The foraminiferal assemblage present in the clay section between 240 and 210 cm in Core 42 is similar in composition to the assemblage encountered in the clay at the base of Core 8 (Fig. 13). In both cases, *Epistominella vitrea* and *Ammonia beccarii* are the predominant forms (Fig. D-17). However, there are significant numbers (12.5%) of the genus *Brizalina* present in the clay from Core 42 that are not present in the 433 and 400 cm samples of Core 8.

The benthonic genera throughout the remainder of Core 42 are indicative of an inner continental shelf environment (Fig. D-19). The change from an inner continental shelf fauna to an outer shelf fauna that usually occurs in the upper sections of the cores from this area does not occur in Core 42. The characteristic increase in the planktonic-benthonic ratio that accompanies this influx of deeper water benthonics also is absent in the upper section of Core 42 (Fig. D-18). This indicates that the 0 cm sample from this core is not the true top of the sediment column. Further evidence for this interpretation is the absence of the *Globorotalia cultrata* group in the samples from Core 42.

The relative abundance of *Amphistegina* increases from 0.6% at



carbonate sand and algal nodules

gray-green clay

ICS- inner continental shelf

DM- deltaic marine

Fig. 13-The planktonic facies, benthonic facies and lithology of Core 42.

200 cm to 12.5% at 100 cm where it is the predominant genus. Above 100 cm the percentage of *Amphistegina* decreases. It constitutes 6.0% of the total assemblage at 0 cm (Fig. D-20).

Core 24 (Table C-5)

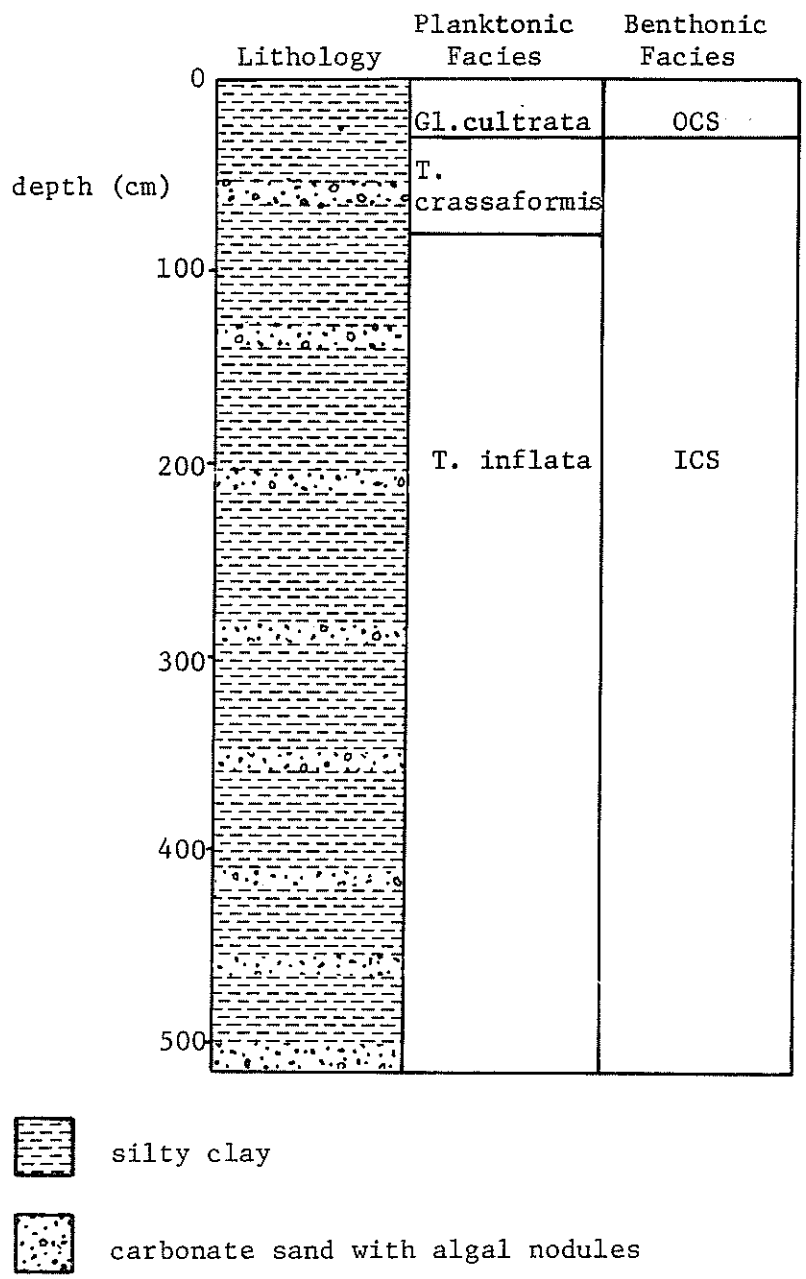
The high (0.26-0.55) planktonic-benthonic ratio present throughout the length of Core 24 is consistent with the presence of planktonic foraminifers characteristic of the *Gl. cultrata* Facies (Fig. D-21).

The outer continental shelf genera *Cibicidoides* and *Cassidulina* are abundant in both the 70 and 0 cm samples (Fig. D-22). The lower percentages of these genera at 35 cm is a function of faunal predominance by *Amphistegina* at this level. *Amphistegina* makes up 48.4% of both the total assemblage and the benthonic assemblage at 35 cm (Fig. D-23).

Core 22 (Appendix B; Table C-6; Fig. 14)

The planktonic-benthonic ratio generally decreases between 514 and 280 cm within the *T. inflata* Facies (Fig. D-24). The outer continental shelf genera are also slightly more abundant within this interval than they are throughout the remainder of the *T. inflata* Facies (Fig. D-25). The variation in these parameters between 514 and 280 cm seems to indicate a minor fluctuation in sea level during the interval of time represented by the *T. inflata* Facies (Fig. 14).

Between 280 and 30 cm the inner shelf form *Rosalina* is the



OCS- outer continental shelf

ICS- inner continental shelf

Fig. 14-The planktonic facies, benthonic facies and lithology of Core 22.

predominant benthonic foraminifer (Fig. D-26). Nonionella and Epistominella are also present, though not abundant within this interval. In the 0 cm sample the outer shelf forms Cibicidoides and Euuvigerina become the predominant benthonic genera. The increase in relative abundance of these forms is consistent with the increase in the planktonic benthonic ratio and appearance of Gl. cultrata.

Between 514 and 60 cm the predominant silty clay contains layers (1-5 cm thick) of coarse carbonate sand. These layers are composed mainly of algal and coral fragments. The benthonic foraminifers and planktonic-benthonic ratio indicate this interval between 514 and 60 cm was deposited during a time when sea level was significantly lower than today. This lower stand of sea level allowed erosion of carbonate sediments from the bank. This eroded material could then have been redeposited on the deep flanks of the structure or on the surrounding level bottom. This mechanism seems to explain the extreme variations in the lithology of Core 22.

RESULTS

Origin of the Deltaic Clay

The clay sections encountered at the bases of Core 8 and Core 42 appear to correspond to the strong reflector visible on the sub-bottom profiles in Figures 15, 16, and 17. The age of this clay cannot be accurately determined due to the lack of planktonic foraminifers and material suitable for radiometric dating. The benthonic foraminifers within this clay are indicative of a shallow deltaic marine environment.

Lehner (1969) and Edwards (1971) have indicated that late Quaternary deltaic deposits are present in the shallow subsurface along this section of the outer continental shelf. This clay may have been deposited during the latest major lowering of sea level. If this were the case, and the bank was a topographic prominence at that time, then these deltaic deposits would occur on only the lower flanks of the structure. The pinnacles of the bank should have been subaerially exposed if sea level had fallen sufficiently to allow deltaic sedimentation on the present-day outer continental shelf. This rapid influx of terriginous sediment would have been unfavorable to the growth of a reefal fauna which may have inhabited the West Flower Garden Bank prior to the last major lowering of sea level.

The sub-bottom profile in Figures 16 and 17, and others from the West Flower Garden Bank (see Edwards, 1971) indicate that the

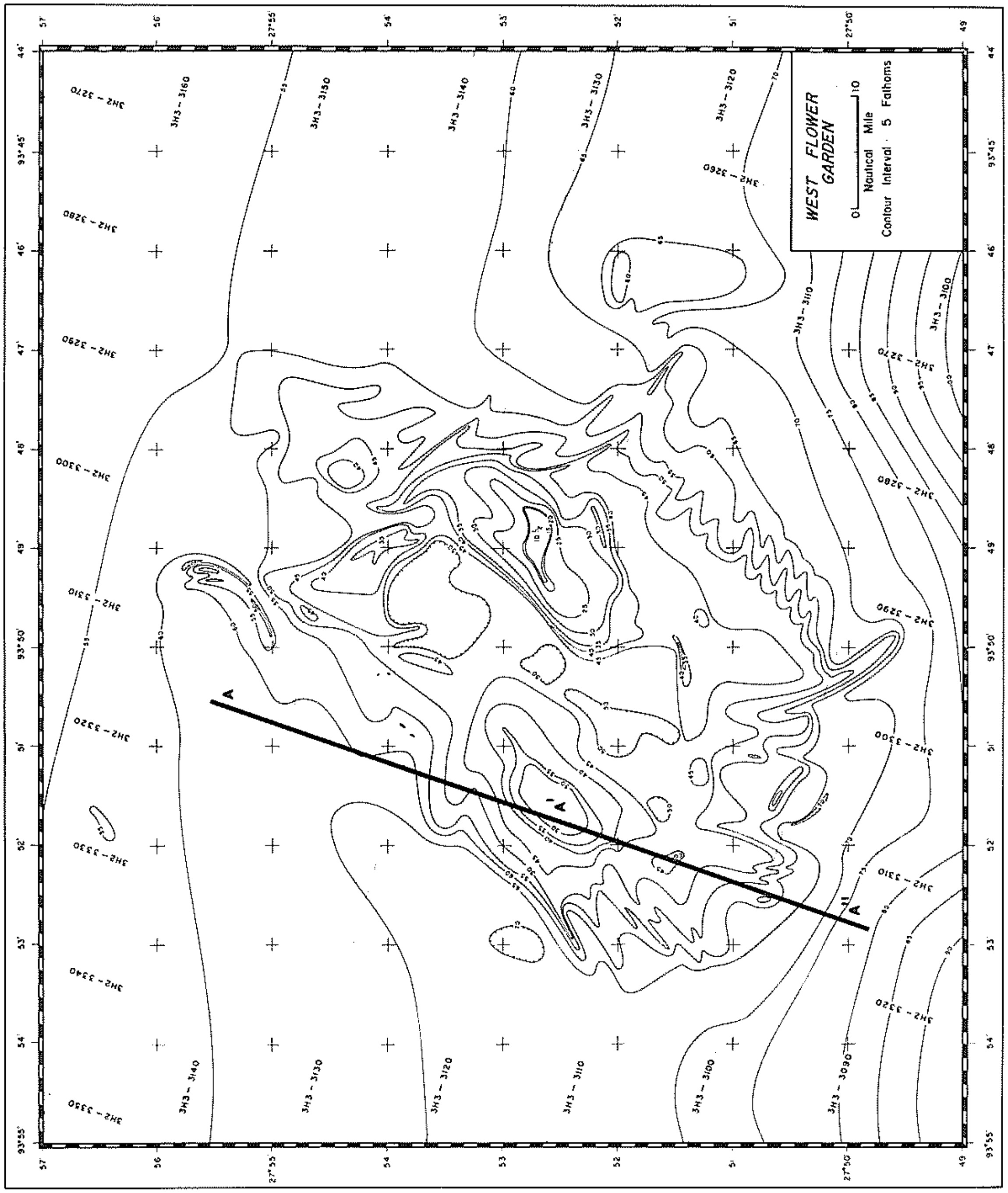


Fig. 15-Location of sub-bottom profile displayed in Figures 16 and 17.

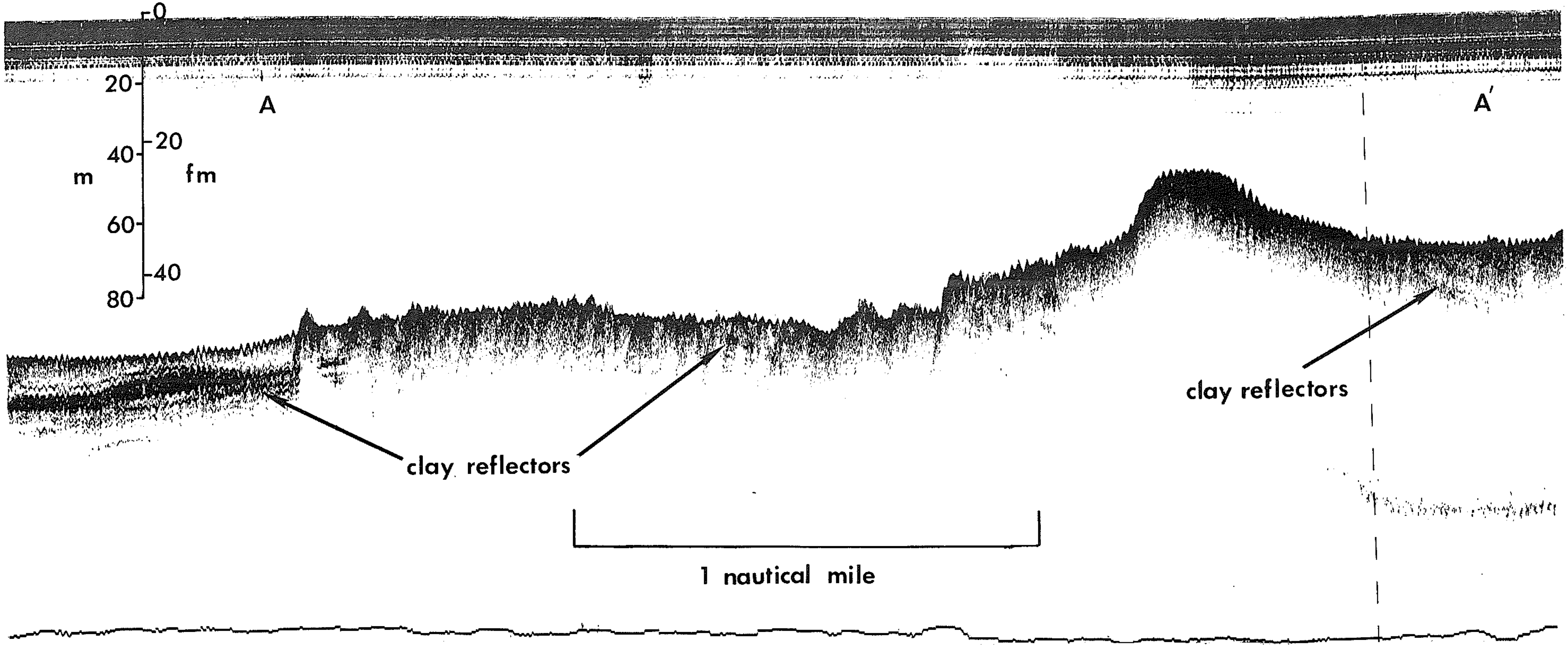


Fig. 16-Sub-bottom profile A-A'.

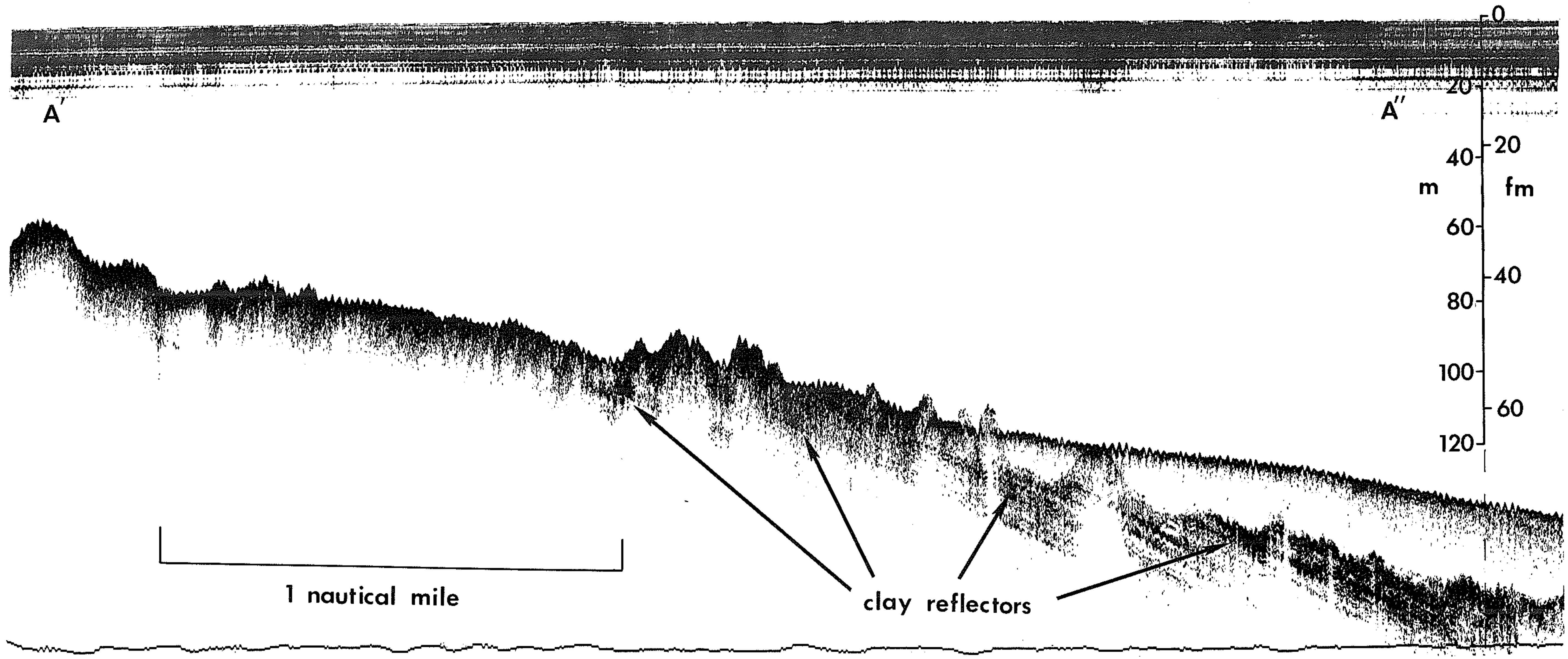


Fig. 17-Sub-bottom profile A'-A".

clay unit underlies the thin carbonate sediment on all parts of the bank. Only traces of the dipping reflectors appear in the subsurface from the shallower areas of the bank due to the acoustical opacity of the coarse carbonate sediment (Figs. 16 and 17).

The data presented above suggest that this clay is older than the late Quaternary. The unit could have been forced up by the movement of the underlying salt, as indicated by the anticlinal shape of its reflectors, and exposed by late Quaternary erosion. The relief on the top of the clay unit (Fig. 17), evident on the southern flank of the structure indicates erosion of this unit during a lower stand of sea level.

This explanation does not require an upward movement of the salt during the late Quaternary. As sea level was lower during this time, erosion of an overlying unit could have occurred without a recent vertical movement of the salt.

Establishment of Reefal Community

As sea level rose and began to cover the flanks of the West Flower Garden Bank, the West Indian reefal foraminifers and coralline algae began to flourish. These forms, along with the foraminifers characteristic of the inner continental shelf, compose the majority of the sediment. This coarse, predominantly carbonate sediment lies unconformably on the clay. Further evidence for this unconformity is provided by differential weathering of foraminifers across the lithologic boundary and abundant glauconite and large, well-rounded quartz grains found in some samples from the top of the clay.

During the time represented by the _T. inflata_ Facies, sea level rose to a level approximately 73 m (40 fm) below present day sea level (Fig. 18B). This estimation of sea level is based on the absence of the _T. inflata_ Facies in cores taken in less than 73 m of water.

Amphistegina is present in abundance within the _T. inflata_ Facies from Cores 8, 40, and 42. The depth of water at each of these stations is presently greater than the 40 m deep limit for abundant living _Amphistegina_. However, if sea level stood at -73 m this would allow _Amphistegina_ to flourish at these sites.

Poag (1972) has stated that the cooler water temperatures during the interval of time represented by the _T. inflata_ Facies reduced the numbers of _Amphistegina_ within this facies of the Phleger Bank Core. The presence of abundant _Amphistegina_ in Cores 8, 40, and 42 indicates that perhaps the water temperature did not control the abundance of this genus within this facies. Sieglie (1968) reported abundant _Amphistegina_ in a glauconitized fauna from submerged reefs off the coast of Puerto Rico. These reefs and associated benthonic faunas flourished during a lower stand of sea level caused by cooler climates. It is possible that the _Amphistegina_ within the _T. inflata_ Facies from the West Flower Garden Bank cores are a relict assemblage from a previous warmer

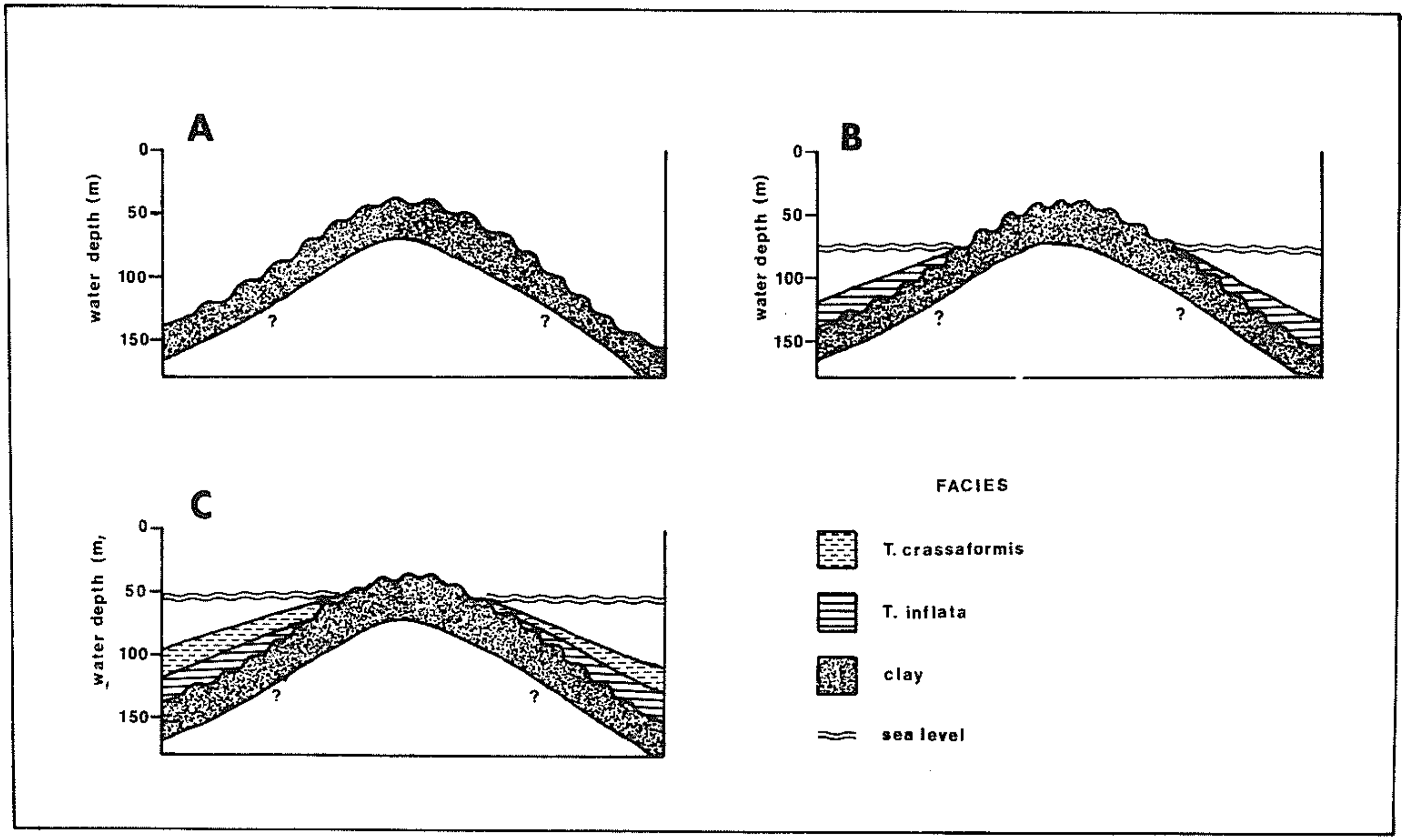


Fig. 18-Generalized reconstruction of the late Pleistocene history of the West Flower Garden Bank.

A. Prior to the latest major rise in sea level.
B. The -73 sea level at the T. inflata-T. crassaformis Facies boundary.
C. The -53 m sea level at the T. crassaformis-Gl. cultrata Facies boundary.

interval. However, their preservation appears to be consistent with that of the remainder of the assemblage from each of these samples. It appears that the vertical fluctuations in the abundance of *Amphistegina* within the West Flower Garden Bank cores are a response to changes in sea level rather than climatic variations.

Amphistegina is absent within the *T. inflata* Facies of Core 22. A -73 m sea level would have covered this core site to a depth of 46 m.

There is a predominance of inner continental shelf benthonic foraminifers within the *T. inflata* Facies from Cores 8, 22, 40, and 42. This, along with the low planktonic-benthonic ratio present within this interval, is consistent with the -73 m sea level at the top of the *T. inflata* Facies.

The clay was not encountered below the *T. inflata* Facies in Core 22 or 40. Core 22, 514 cm in length, was recovered from a depth of 119 m (65 fm). This would indicate that more than 514 cm of sediment were deposited at this site since the rise in sea level and subsequent burial of the clay unit. Core 40, 440 cm in length, was recovered from a depth of 91 m (50 fm). The top of the *T. inflata* Facies is placed at 240 cm above the bottom of the core. At this site more than 240 cm of sediment were deposited during the *T. inflata* interval.

Clay was encountered in Cores 8 and 42, which were recovered from shallower water depths than Cores 40 and 22. For this reason they should be closer to the updip pinchout of the sediment deposited during the T. inflata Facies (Fig. 19).

Attainment of Maximum Sea Level

During the T. crassaformis interval, sea level continued to rise and by the top of this interval stood at approximately -53 m (29 fm) (Fig. 18C). In cores that also contain the T. inflata Facies, the contact between the 2 facies (T. inflata and T. crassaformis) is conformable.

In Core 27, recovered from a depth of 64 m (35 fm), the sediment of the T. crassaformis Facies is believed to lie unconformably on the older clay. Though the clay itself was not present at the base of Core 27, there is a small influx of two genera characteristic of a deltaic marine environment, which is attributed to reworking of the clay. If this clay were present below the 190 cm of sediment penetrated by Core 27, it could explain the poor sediment recovery at this site.

Core 37, 400 cm long, was recovered from a depth of 113 m (62 fm) on the northwest side of the bank. It did not penetrate the T. inflata Facies. The interval from 400 to 60 cm contains the T. crassaformis Facies. It is important to note that, although the predominant genera are characteristic of an inner shelf environment, this facies contains significant numbers of deltaic marine benthonic genera. The thickness of sediment and the presence of deltaic marine foraminifers within the T. crassaformis Facies are to be expected as Core 37 is located on the landward side of

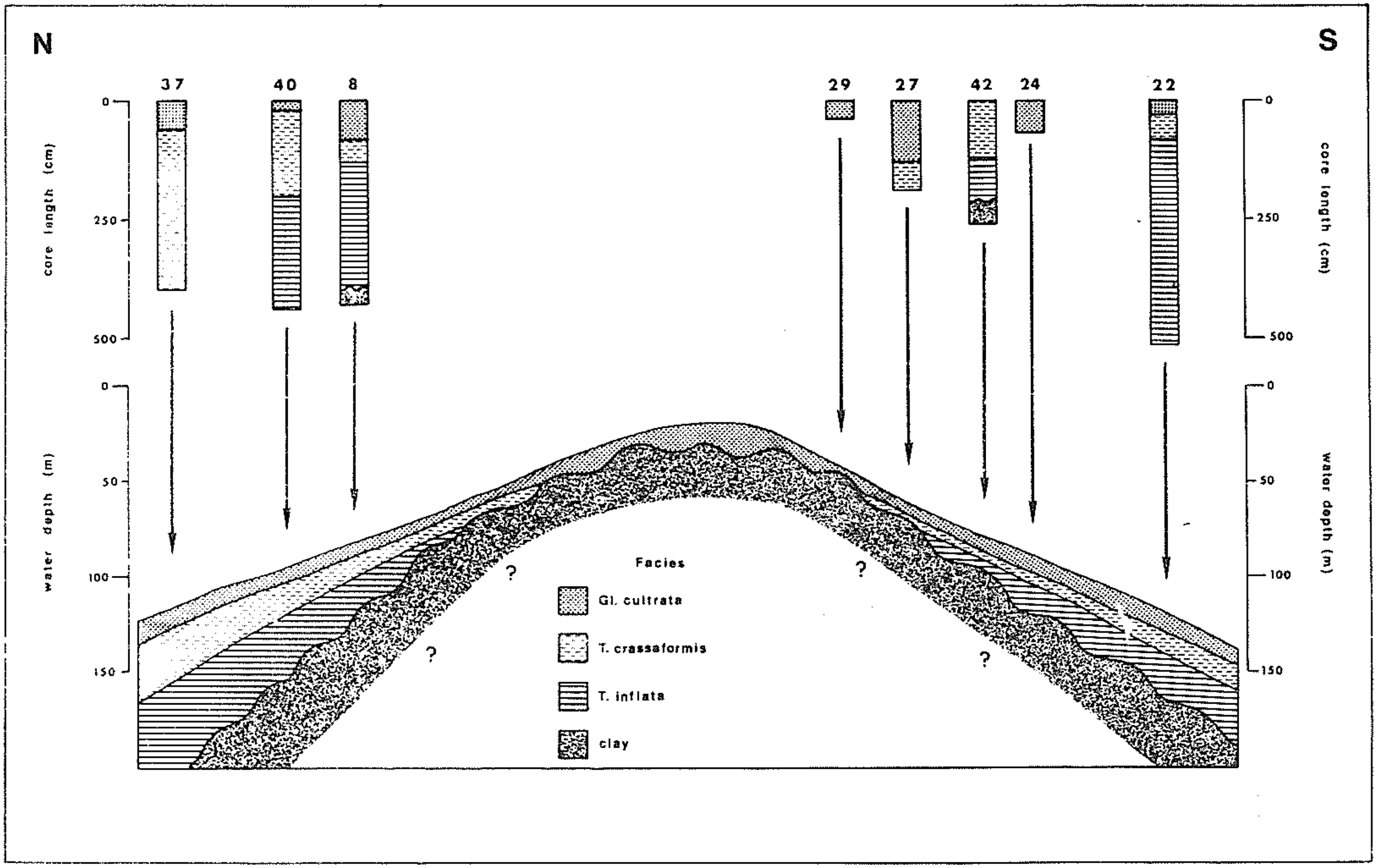


Fig. 19-Generalized cross-section through the West Flower Garden Bank illustrating the relationship of the sediment contained within the three planktonic facies to the underlying clay unit. Thickness of sediment in lower portion of figure is not to scale.

the bank (Fig. 7, p. 18) and thus toward the source of terriginous sediment.

Amphistegina is present in abundance within the *T. crassaformis* Facies of Cores 8, 27, and 42. Both Core 8 and Core 42 contain significant numbers of *Amphistegina* within the *T. inflata* Facies. This rise in sea level during the *T. crassaformis* interval did not cover Sites 8 and 42 with greater than 40 m (22 fm) of water. The presence of a -53 m sea level during deposition of the youngest sediments of the *T. crassaformis* Facies is consistent with such an interpretation as the water depth would have been 27 m (15 fm) over Site 8 and 29 m (16 fm) over Site 42.

Core 40, recovered from a depth of 91 m (50 fm) contains abundant *Amphistegina* within the *T. inflata* Facies. In the *T. crassaformis* Facies of this core *Amphistegina* becomes rare. A sea level at -53 m would place the water depth at Site 40 at 38 m (21 fm), close to the 40 m (22 fm) deep limit for abundant *Amphistegina*.

The low planktonic-benthonic ratio and the predominant benthonic foraminifers from the *T. crassaformis* Facies are indicative of an inner continental shelf environment.

Holocene Facies

The *Globorotalia cultrata* Facies is characterized by an influx of warm water planktonic foraminifers, an increase in the planktonic-benthonic ratio, and a predominance of outer continental shelf benthonic genera. All this indicates a climatic warming causing a decrease in glacial ice and a corresponding accelerated rise in sea level.

Since deposition of the _T. crassaformis_ Facies, sea level has risen approximately 53 m. It was during this interval that the West Flower Garden Bank became completely submerged. The submergence of the crests of the bank by the warmer waters of the Holocene allowed the reef building corals, which cap the main pinnacle of the structure, to flourish.

Core 29, 40 cm in length, was recovered from a depth of 42 m (23 fm). The bottom of this core contains abundant glauconite and rounded quartz grains. Though there was no clay recovered in this core, it appears that the 40 cm section immediately overlies the clay unit. The entire 40 cm of Core 29 contains the _Gl. cultrata_ Facies. This indicates that deposition at this level of the bank did not occur during the _T. inflata_ and _T. crassaformis_ intervals.

Amphistegina is present in abundance within the _Gl. cultrata_ Facies of Cores 8, 29, 27, and 24. The abundant _Amphistegina_ in Cores 8, 24, and 27 probably were living early in the _Gl. cultrata_ interval. These cores were all recovered from water depths greater than the 40 m deep limit for abundant living _Amphistegina_. The percentage of _Amphistegina_ decreases in the surface samples from each of these cores. Thus, it appears that members of this genus flourished during a lower stand of sea level within the Gl. cultrata interval.

Core 29 contains abundant Amphistegina at the top of the core. As this core was recovered from a depth of 42 m (23 fm) these forms were probably living late in the Gl. cultrata interval.

The other benthonic foraminifers present within the Gl. cultrata interval are representative of an outer continental shelf environment, although the water depths at many of the core sites are inner continental shelf depths. It appears that, unless there has been a recent upward movement of the salt, the change from an inner to an outer continental shelf level bottom fauna around the bank has influenced the composition of the benthonic fauna at the shallower stations on the bank.

Correlation with Phleger Bank

The events cited above show excellent correlation with events inferred from an examination of foraminiferal remains in a core from Phleger Bank (Poag, 1972). This bank is located on the upper continental slope approximately 120 nautical miles east of the West Flower Garden Bank (Fig. 1, p. 3); its crest is at -124 m. Poag (1972) identified the major planktonic foraminiferal facies (Fig. 3, p. 8) and determined paleobathymetry, based on a core taken near the crest (-128 m). From Poag's study, one may estimate the sea level at the boundaries of the various planktonic facies and compare them with the West Flower Garden

Bank data.

The lower *T. inflata* Facies and *Gl. flexuosa* Facies of the Phleger Bank core are absent in the West Flower Garden Bank cores (Fig. 20). These facies are probably present above the clay section off the flanks of the bank. Their absence from the cores in which the clay was penetrated is attributed to the erosion that occurred during the latest lowering of sea level. The unconformities present at the base of the uppermost *T. inflata* Facies are only in part correlative due to the difference in elevation of the 2 banks.

The three planktonic facies present on the West Flower Garden Bank correspond to the three planktonic facies present between 225 and 0 cm in the Phleger Bank core (Fig. 20).

Figure 21 demonstrates the close correspondence between the position of sea level at the top of the *T. inflata* Facies and the base of the *Gl. cultrata* Facies at West Flower Garden Bank and Phleger Bank. There is a 7 m difference in the estimated sea level at the top of the *T. inflata* Facies from the 2 banks. The difference is 11 m at the base of the *Gl. cultrata* Facies. This is remarkable correspondence in light of the fact that sea levels determined from the Phleger Bank core are based on benthonic depth indicators alone. Although these indicators have been used for many years, they hardly provide an absolute paleo-water depth. Instead, they allow a reasonably accurate estimation of the paleoenvironment. The fact that both sea levels determined from

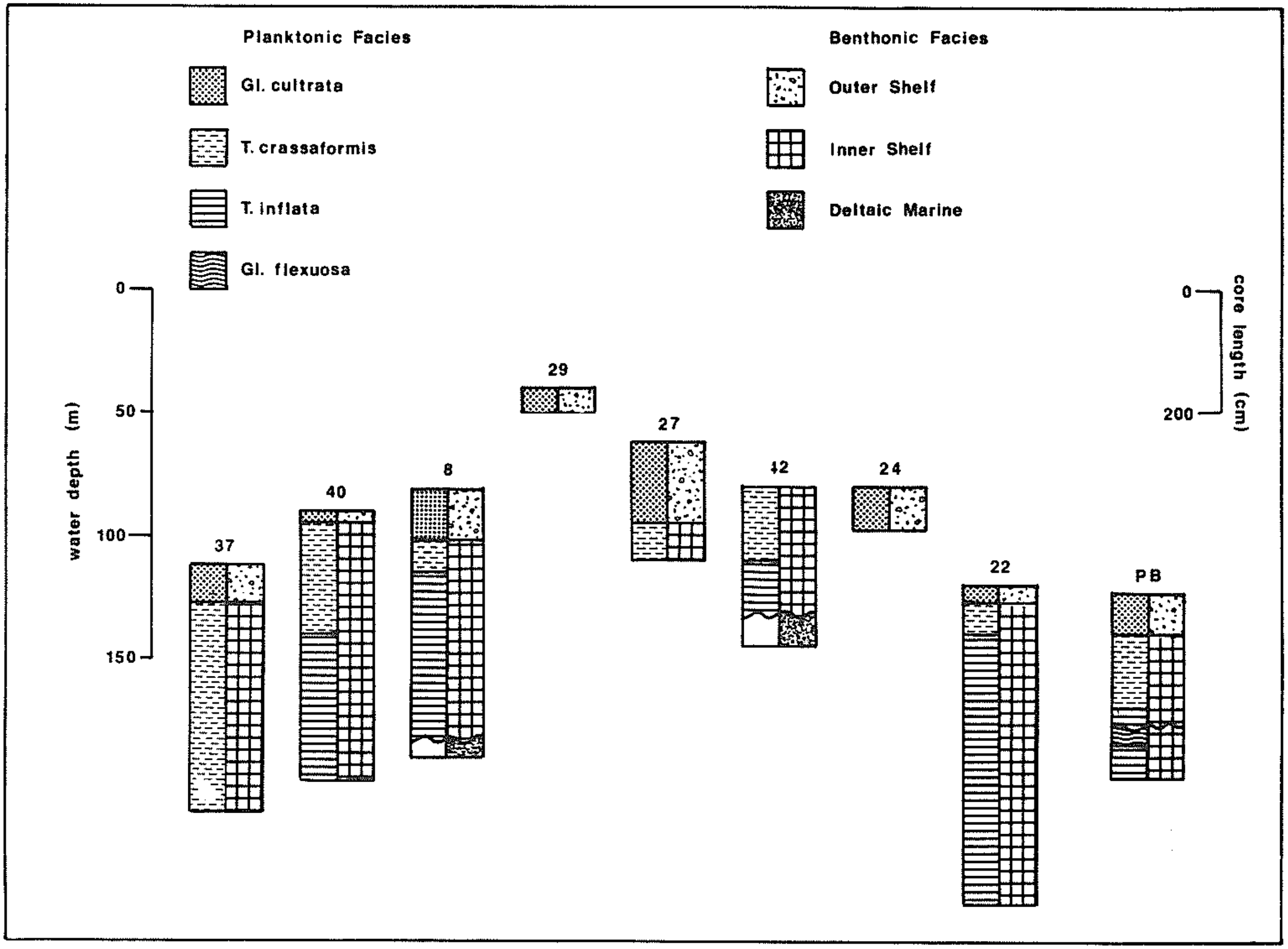


Fig. 20-The planktonic and benthonic facies relationships in the cores from the West Flower Garden Bank and the Phleger Bank core.

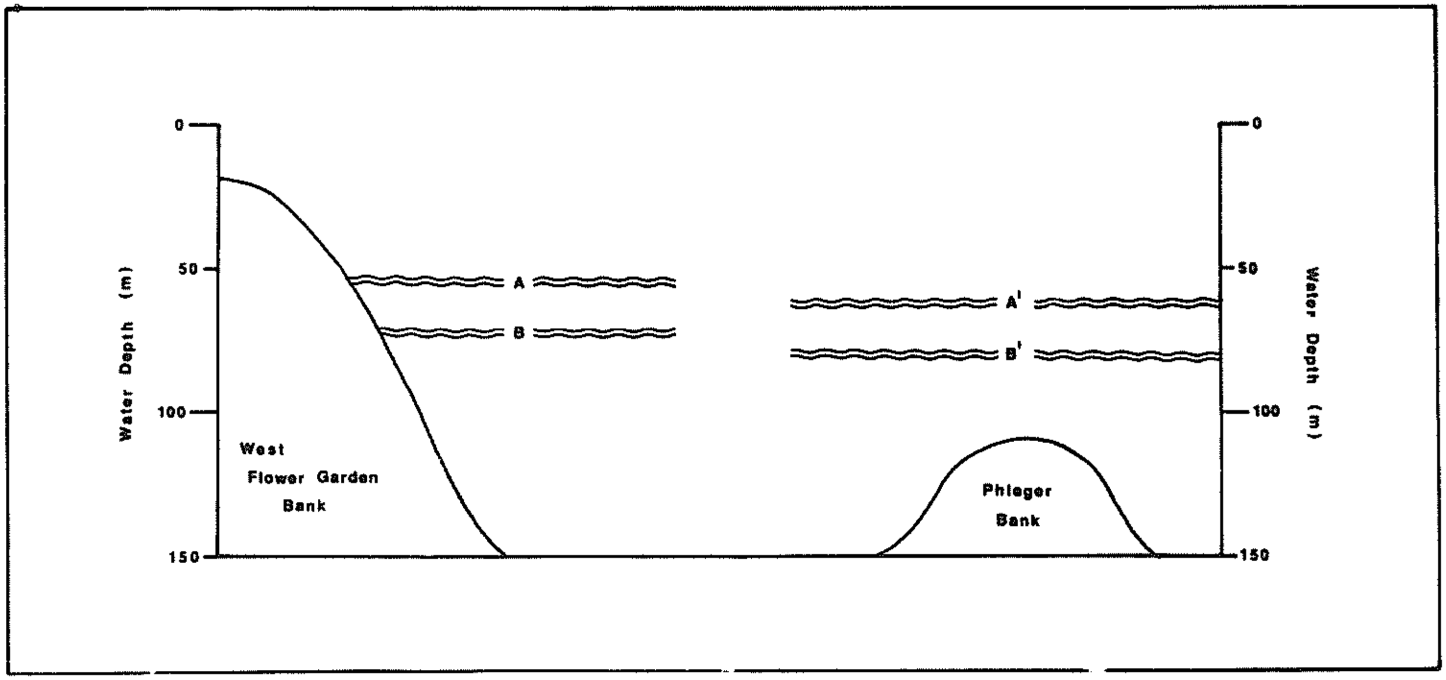


Fig. 21-Correlation of sea levels between the West Flower Garden Bank and Phleger Bank. A and A' are the sea levels at the base of the _Gl. cultrata_ Facies at West Flower Garden Bank and Phleger Bank, respectively. B and B' are the sea levels at the top of the _T. inflata_ Facies from the two banks.

the Phleger Bank core are slightly lower than those from the West Flower Garden Bank cores may result from the greater subsidence rate of the shelf and slope in the vicinity of the Mississippi River delta.

Radiocarbon Chronology

With increasing age, the chance of carbonate sediment becoming contaminated with recent carbon increases. Thus, in an older sample, the probability of the radiocarbon date being significantly younger than the true age becomes greater. Broecker and Bender (1972) stated that the accuracy of radiocarbon ages between 15,000 and 25,000 years B.P. are subject to moderate suspicion and ages over 25,000 years B.P. are highly suspect.

The foraminiferal faunas and radiocarbon dates (Fig. 22) indicate that sea level began to rise around the West Flower Garden Bank prior to 30,000 years B.P. This inference is based on dates from the *T. inflata* Facies of Cores 8, 22, and 42. Although the 143 cm sample from Core 42 may be significantly older, the 30,000 year B.P. date represents its minimum age. The sea level curve of McFarlan (1962) also shows a major rise in sea level prior to 30,000 years B.P. The sea level curve of Ballard and Uchupi (1970), however, shows sea level stood at nearly its present level between 30,000 and 40,000 years B.P. The poor correlation between these data is undoubtedly in part due to the problems involved with the radiocarbon dating of material older than 15,000 years.

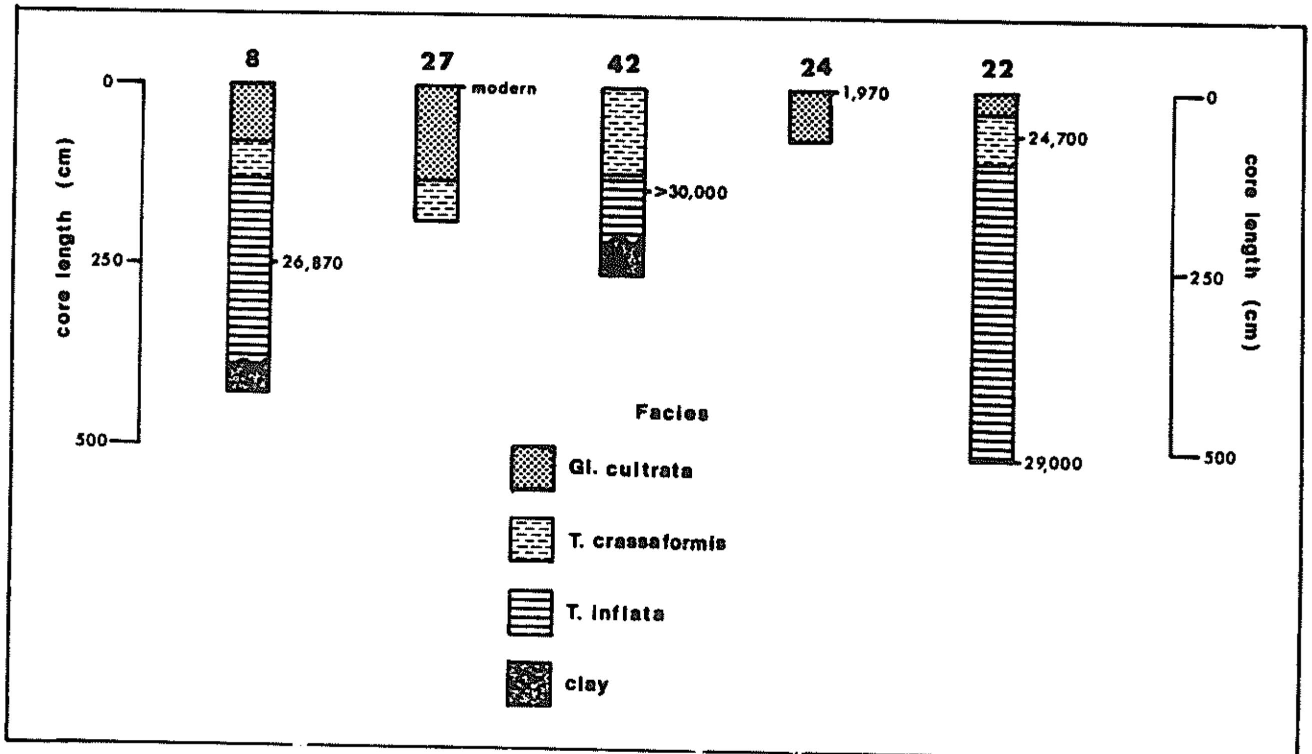


Fig. 22-Radiocarbon dates from West Flower Garden Bank cores. The values indicate the number of years B.P. The date of 24,700 years B.P. at 60 cm in Core 22 is not significant as it appears that the dated material has been reworked. See Appendix F for additional information regarding the radiocarbon dates.

Sea level continued to rise over the West Flower Garden Bank during the *T. inflata* and *T. crassaformis* intervals and at the base of the *Gl. cultrata* interval stood at -53 m. In this area, the boundary between the cooler *T. crassaformis* Facies and the overlying *Gl. cultrata* Facies represents the Pleistocene-Holocene boundary (Poag, 1972).

Curray (1960), McFarlan (1962), Ballard and Uchupi (1970), and Poag (1972) dated the -60 m sea level at 10,000-12,000 years B.P., a time accepted by a number of authors as the Pleistocene-Holocene boundary (Bandy, 1967; Ewing, Ericson, and Heezen, 1958; Poag and Sweet, 1972). This -60 m sea level is close to the -53 m sea level which occurred at 10,000-12,000 years B.P. in the area of the West Flower Garden Bank.

SUMMARY AND CONCLUSIONS

The West Flower Garden Bank existed as a topographic prominence prior to the latest major rise in sea level of the late Quaternary. Erosion of the bank during this lower stand of sea level exposed a previously buried clay unit which, based on the anticlinal pattern of its dipping reflectors, (Figs. 16 and 17, pp. 39 & 41) had been previously deformed by vertical movement of the underlying salt. These clay reflectors indicate that this unit underlies the coarse carbonate sediment on all areas of the bank. The foraminiferal assemblage within this clay stratum is characteristic of a deltaic marine environment.

As sea level began to rise over the flanks of the West Flower Garden Bank, the sediment of the *T. inflata* Facies was deposited unconformably above the clay. Due to the inaccuracy of radiocarbon dates older than 15,000 years, the exact time at which this transgression began cannot be determined, but the minimum age of this event is 30,000 years B.P. The *T. inflata* Facies is absent in cores recovered from depths shallower than 73 m. It is believed that the sea reached this -73 m level at the boundary between the *T. inflata* Facies and the overlying *T. crassaformis* Facies. This interpretation is supported by the abundance of *Amphistegina* and other benthonic depth indicators within the *T. inflata* Facies.

The sediment of the *T. crassaformis* Facies lies conformably on that of the *T. inflata* Facies from cores taken deeper than 73 m.

Between -73 m and -53 m, this facies lies unconformably over the clay unit. The absence of this facies in cores recovered from depths shallower than 53 m indicates a -53 m sea level at the top of this facies.

The uppermost planktonic facies is the *Gl. cultrata* Facies, characterized by an influx of the warm water indicators of the *Gl. cultrata* group. During the deposition of this facies, sea level completely covered the West Flower Garden Bank and rose to its present level. Whereas the predominant benthonic foraminifers within the *T. inflata* and *T. crassaformis* Facies were indicative of an inner shelf environment, the predominant benthonic indicators within the *Gl. cultrata* Facies are characteristic of an outer continental shelf environment.

The events inferred from the West Flower Garden Bank cores display excellent correlation with those recognized by Poag (1972) from a core taken on Phleger Bank. Poag identified the planktonic facies and determined the paleobathymetry, allowing a comparison of sea levels at the boundaries of the planktonic facies between the 2 banks. The estimated sea levels at the *T. inflata* Facies-*T. crassaformis* Facies boundary and the *T. crassaformis* Facies-*Gl. cultrata* Facies boundary from the 2 banks vary by 7 m and 11 m, respectively (Fig. 21). At each boundary the estimated sea level is slightly lower in the Phleger Bank core, possibly reflecting a greater subsidence rate of the shelf and slope in the vicinity of the Mississippi delta.

Several authors (Curray, 1960; McFarlan, 1961; Ballard and Uchupi, 1970; Poag, 1972) have indicated that sea level reached a -60 m level at approximately 10,000-12,000 years B.P., the commonly accepted age of the Pleistocene-Holocene boundary. Since the inferred sea level at the base of the *Gl. cultrata* Facies (-53 m) is near -60 m and the planktonic foraminifers that define the facies indicate a significant warming trend, this level is believed to represent the Pleistocene-Holocene boundary in the cores from the West Flower Garden Bank.

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APPENDIX A

DATA FROM SURFACE SAMPLES

Station	Water depth (m)	Planktonic-Benthonic ratio	% *Amphistegina*
2	104	1.16	0.0
3	46	0.25	44.6
4	66	0.15	35.7
7	86	0.75	5.3
8	85	0.54	22.5
13	97	0.82	5.4
15	84	0.90	2.9
17	113	1.46	2.2
20	38	0.15	37.9
21	99	1.66	0.3
22	90	1.28	0.3
23	99	1.62	0.3
25	79	0.88	7.2
26	95	0.58	11.2
29	49	0.10	39.7
30	79	0.62	17.2
32	90	1.20	0.0
33	86	1.06	3.8
35	95	0.85	9.3
37	110	1.09	0.9
38	95	0.90	13.4
43	82	1.15	3.7

APPENDIX B

SUMMARY OF CORE DATA

Core 37

Location: north side of West Flower Garden Bank (Fig. 7)

Water depth: 113 m (62 fm)

Length: 400 cm

Lithology: silty clay (Fig. 9)

Sample Points: 0, 40, 80, 170, 200, 230, 270, 300, 360, and 400 cm

Significant faunal variations: (Table C-1; Fig. 9)

400-60 cm

a) The planktonic-benthonic ratio is low, varying between 0.04 and 0.10 (Fig. D-1).

b) There is a predominance of inner continental shelf benthonic genera (Fig. D-2).

c) The planktonic foraminifers are indicative of the *Turborotalia crassaformis* Facies.

60-0 cm

a) The planktonic-benthonic ratio increases from 0.04 (80 cm) to 0.96 (0 cm).

b) The predominant benthonic foraminifer is characteristic of an outer continental shelf environment (Fig. D-3).

c) The planktonic foraminifers are indicative of the *Globorotalia cultrata* Facies.

Core 40

Location: north side of West Flower Garden Bank (Fig. 7)

Water depth: 91 m (50 fm)

Length: 440 cm

Lithology: medium to coarse carbonate sand with algal nodules and mollusc shells scattered throughout the entire section (Fig. 10)

Sample points: 0, 40, 80, 120, 155, 200, 273, 309, 330, 360, 400, and 440 cm

Significant faunal variations: (Table C-2; Fig. 10)

440-200 cm

a) The planktonic-benthonic ratio is low, varying between 0.02 and 0.13 (Fig. D-5).

b) The benthonic genera indicate an inner continental shelf environment (Fig. D-6).

c) The planktonic foraminifers are indicative of the *Turborotalia inflata* Facies.

200-20 cm

a) The planktonic-benthonic ratio remains low varying between 0.04 and 0.07.

b) The benthonic foraminifers are characteristic of the inner continental shelf.

c) The planktonic foraminifers present are indicative of the _Turborotalia_ _crassaformis_ Facies.

20-0 cm

a) The planktonic-benthonic ratio increases from 0.03 (40 cm) to 0.32 (0 cm).

b) The benthonic foraminifers are indicative of an outer continental shelf environment (Fig. D-7).

c) The planktonic foraminifers are characteristic of the _Globorotalia_ _cultrata_ Facies.

Core 8

Location: north side of the West Flower Garden Bank (Fig. 7)

Water depth: 81 m (44 fm)

Length: 433 cm

Lithology: 433-393 cm stiff gray-green clay (Fig. 11)

393-0 cm medium to coarse carbonate sand with algal nodules

Significant faunal variations: (Table C-3; Fig. 11)

433-393

a) The planktonic-benthonic ratio is very low within this clay section varying between 0.02 and 0.03.

b) The predominant benthonic genera are characteristic of a deltaic marine environment (Fig. D-9).

c) There are no diagnostic planktonic foraminifers present within this interval.

393-130

a) The planktonic-benthonic ratio is low fluctuating between 0.07 and 0.22 (Fig. D-10).

b) The benthonic foraminifers present are characteristic of an inner continental shelf environment (Fig. D-11).

c) The planktonic foraminifers present are indicative of the Turborotalia inflata Facies.

130-80 cm

a) The planktonic-benthonic ratio remains low.

b) The benthonic foraminifers are characteristic of the inner continental shelf.

c) The planktonic foraminifers present place this section within the Turborotalia crassaformis Facies.

80-0 cm

a) The planktonic-benthonic ratio increases from 0.08 at 100 cm to 0.85 at the top of Core 8.

b) The benthonic foraminifers are characteristic of the outer continental shelf (Fig. D-12).

c) The planktonic foraminifers in this section are indicative of the Globorotalia cultrata Facies.

Core 27

Location: south side of the western pinnacle of West Flower Garden Bank (Fig. 7)

Water depth: 64 m (35 fm)

Length: 190 cm

Lithology: medium to coarse carbonate sand with algal nodules (Fig. 12)

Sample points: 0, 50, 110, 190 cm

Significant faunal variations: (Table C-4; Fig. 12)

190-130 cm

a) The planktonic-benthonic ratio is moderately high; varying between 0.40 and 0.66 (Fig. D-16).

b) The benthonic genera indicate inner continental shelf environment.

c) The planktonic foraminifers are indicative of the *Turborotalia crassaformis* Facies.

130-0 cm

a) The planktonic benthonic ratio increases to 1.07 at the top of Core 27.

b) The benthonic genera are characteristic of the outer continental shelf (Fig. D-14).

c) The planktonic foraminifers present are those of the *Globorotalia cultrata* Facies.

Core 29

Location: southwest side of the main pinnacle of West Flower Garden Bank

Water depth: 42 m (23 fm)

Length: 40 cm

Lithology: medium to coarse carbonate sand with algal nodules.

Sample points: 0 and 40 cm

Significant faunal variations: (Table C-4)

40-0 cm

a) The planktonic-benthonic ratio does not change significantly within this interval.

b) The benthonic foraminifers are characteristic of the outer continental shelf.

c) The planktonic foraminifers present are indicative of the *Globorotalia cultrata* Facies.

Core 42

Location: south side of the West Flower Garden Bank (Fig. 7)

Water depth: 82 m (45 fm)

Length: 260 cm

Lithology: 260-210 cm stiff gray-green clay (Fig. 13)

210-0 cm coarse carbonate sand with algal nodules

Sample points: 0, 60, 100, 143, 170, 200, and 240 cm

Significant faunal variations: (Table C-5; and Fig. 13)

260-210 cm

a) The planktonic-benthonic ratio is low;
   0.02 in the 240 cm sample.

b) The benthonic foraminifers indicate a deltaic marine environment (Fig. D-17).

c) There are no diagnostic planktonic foraminifers.

210-120 cm

a) The planktonic-benthonic ratio is low, varying between 0.04 and 0.18.

b) The benthonic foraminifers are characteristic of an inner continental shelf environment.

c) The planktonic foraminifers are characteristic of the *Turborotalia inflata* Facies.

120-0 cm

a) The planktonic-benthonic ratio varies between 0.09 and 0.13 (Fig. D-18).

b) The benthonic genera are indicative of an inner continental shelf environment (Fig. D-19).

c) The planktonic foraminifers present place this interval within the *Turborotalia crassaformis* Facies.

Core 24

Location: south side of West Flower Garden Bank (Fig. 7)

Water depth: 82 m (45 fm)

Length: 70 cm

Lithology: coarse carbonate sand and algal nodules

Sample points: 0, 35, and 70 cm

Significant faunal variations: (Table C-5)

70-0 cm

a) The planktonic benthonic ratio is high varying between 0.26 and 0.55 (Fig. D-21).

b) The benthonic foraminifers indicate an outer continental shelf environment (Fig. D-22).

c) The planktonic foraminifers are characteristic of the *Globorotalia cultrata* Facies.

Core 22

Location: south side of West Flower Garden Bank (Fig. 7)

Water depth: 119 m (65 fm)

Length: 514 cm

Lithology: 514-60 cm silty clay with thin layers of coarse carbonate sand (Fig. 14)

60-0 cm silty clay

Sample points: 0, 60, 100, 140, 165, 200, 240, 280, 320, 360, 400, 460, and 514 cm

Significant faunal variations: (Table C-6; Fig. 14)

514-80 cm

a) The planktonic-benthonic ratio varies between 0.26 and 0.05 (Fig. D-24).

b) The predominant benthonic foraminifers are characteristic of an inner continental shelf fauna (Fig. D-26).

c) The planktonic foraminifers are indicative of the *Turborotalia inflata* Facies.

80-30 cm

a) The planktonic-benthonic ratio increases from 0.11 at 100 cm to 0.19 at 60 cm.

b) The benthonic foraminifers are indicative of an inner continental shelf environment.

c) The planktonic foraminifers are characteristic of the *Turborotalia crassaformis* Facies

30-0 cm

a) The planktonic-benthonic ratio reaches 1.11 at 0 cm.

b) The benthonic foraminifers are characteristic of an outer continental shelf fauna (Fig. D-25).

c) The planktonic foraminifers are indicative of the *Globorotalia cultrata* Facies.

APPENDIX C

FAUNAL COMPOSITION OF CORES

Table C-1: Faunal composition of Core 37 (in percent).

Genus	Depth in Core (cm)										
	0	40	80	120	170	200	230	270	300	360	400
Ammonia	0.9	2.0	4.5	3.1	4.5	3.6	2.4	1.6	2.2	3.1	0.5
Amphicoryna	0.4										
Amphistegina	1.2	0.6			0.3						0.2
Amphorina	0.2										
Articulina	0.3	0.4	0.5	0.9	0.3	0.3	0.2	0.5	1.0		0.2
Bigenerina	0.9	0.4	0.7	2.2	1.1		0.5	0.5	1.2	1.2	2.2
Brizalina	2.1	4.2		0.6	3.4	0.6	0.5	0.7	1.9	1.2	0.8
Buccella		0.4	0.7	0.6		0.8	1.0	0.5	0.5	0.3	0.5
Bulimina	0.4	1.2	0.5	1.9	0.3	1.1	1.7	3.2	2.4	0.9	4.3
Buliminella	0.2		3.6		2.4	3.6	1.2	1.6	6.1	2.5	0.8
Cancris	0.6	0.6	1.0		0.5	0.8	1.0	0.5	1.2	0.6	0.8
Cassidulina	1.5	0.4				2.8	0.2				0.5
Cellanthus	1.5	6.4	12.6	4.3	10.5	8.9	14.1	11.1	7.2	9.2	8.4
Cibicidoides	6.3	3.0	1.2	1.2	0.3	1.7	1.4	0.9	1.0	1.5	4.9
Cornuspira		0.2								0.6	
Dentalina	0.2										
Elphidium	2.7	2.4	9.3	6.8	5.8	10.8	4.5	6.9	5.1	4.0	5.7
Epistominella	0.3	1.6	2.9	4.9	5.2	4.4	3.8	2.5	3.6	3.7	1.9
Euuvigerina	3.6	2.8	0.3				0.2				0.8
Florilus	1.2	3.0	7.4	3.7	5.8	6.7	4.5	5.5	4.4	4.6	3.0
Fursenkoina		1.2	2.4	1.9	3.7	1.7	1.9	2.1	2.2	1.9	1.1
Gaudryina		0.2									0.5
Globocassidulina	1.5	2.6	3.1	3.1	2.4		2.6	1.2	1.5	4.0	1.1
Hanzawia	2.4	2.6	2.6	2.2	1.1	0.8	2.6	2.1	1.5	0.9	1.9
Höglundina	0.3										

Table C-1 (Continued).

Genus	Depth in Core (cm)										
	0	40	80	120	170	200	230	270	300	360	400
Leibusella	0.4										
Lenticulina	1.2	0.6	0.5	0.3		0.3	0.5		0.2		0.2
Loxostomum	0.3		0.5			0.3	0.2		0.2	0.6	0.8
Marginulina										0.3	
Melonis	0.3				0.3						0.2
Miliolinella		1.0		0.3	0.3		0.5	0.2		0.3	0.5
Neoconorbina					0.5	0.3			0.2	0.3	0.5
Neoeponides	0.2										
Nonionella	0.9	6.8	7.8	9.3	17.6	11.1	9.8	13.6	21.2	12.6	9.7
Oridorsalis	0.3										
Patellina				0.3						0.3	
Peneroplis	0.2				0.8						
Planorbulina	0.3	0.4								0.3	0.2
Planulina	2.7	1.8	3.1	3.1	2.4	0.6	1.0	2.1	1.2	2.5	1.9
Poroeponides	0.2	0.2			0.3					0.3	
Protelphidium	0.2	1.0	3.8	3.1	2.9	2.5	1.9	3.5	2.2	0.6	2.2
Pullenia											0.2
Pyrgo	0.2	1.0	1.4	0.6	1.6	0.8	2.9	2.5	1.5	1.5	2.2
Quinqueloculina	1.8	3.4	4.0	9.0	4.5	6.9	6.4	5.8	6.8	11.4	7.3
Rectobolivina			0.5	1.9	0.8	0.6	0.5	0.2	0.5	0.3	0.5
Reussella	3.0	1.8	0.7	1.9	2.4		2.4	1.2	1.0	1.2	0.5
Rosalina	3.9	7.0	11.2	10.2	6.8	10.0	11.9	12.9	7.2	12.3	7.0
Sagrina		0.8	1.4	0.6	0.3	1.7	0.5	0.9	0.7	0.6	
Sigmoilina	0.3	0.6			0.3						
Sigmoilopsis	0.3	0.4	1.2	0.6	0.3	0.6	1.2	1.5	0.7	0.6	1.1

Table C-1 (Continued).

Genus	Depth in Core (cm)										
	0	40	80	120	170	200	230	270	300	360	400
Siphonina	2.1	0.6	0.5				0.2	0.7		0.6	
Siphotextularia	0.3							0.2	0.2		
Spirillina	0.2			0.3	0.3	0.3					
Spiroloculina	0.6	1.0			0.3	1.1		0.2	0.5		1.1
Stromatorbina	0.2										
Textularia	1.8	2.0	3.6	3.4	1.3	3.9	4.1	3.5	3.9	1.9	8.9
Trifarina	0.6	0.6	0.5	0.3	1.1	0.3	0.2	0.5	0.5	0.6	0.5
Triloculina	0.6	1.0	0.5	0.3	0.8	1.4	1.2	2.1	2.2	1.2	1.6
Tritaxia	0.3	0.6									0.5
Vaginulinopsis	0.3	0.2									
Genus X	0.3	0.6	0.7	0.9	0.3	0.6	0.2	0.7		0.6	1.1
Unidentified agglutinated forms	1.2	0.6		0.3	0.5				0.2		0.2
Unidentified miliolids	0.4	0.4		0.6	0.3						
Other unidentified benthonics	0.9	0.6	1.7	1.2	1.3	1.1	1.2	0.2	1.0	1.5	0.8
Total planktonics	49.1	27.9	3.8	6.8	3.9	7.5	9.1	6.7	5.1	9.5	8.6
Planktonic-benthonic ratio	0.96	0.39	0.04	0.07	0.04	0.08	0.10	0.07	0.05	0.11	0.09

Table C-2: Faunal composition of Core 40 (in percent).

Genus	Depth in Core (cm)												
	0	40	80	120	155	200	237	273	309	330	360	400	440
Ammonia		1.6	1.3	2.5	0.9	1.0			0.3				
Amphicoryna							0.3						
Amphistegina	0.9	1.0			0.6	0.3	0.3	19.6	9.8	15.6	10.0	10.6	13.6
Archaias								0.7	1.6		1.0	2.1	4.0
Articulina	3.0	0.9	0.3	1.8	9.6	0.6	0.5	1.0	5.6	2.7	3.3	5.2	6.8
Bigenerina	0.3	1.6	2.6	2.5	3.2	2.9	2.6	4.7	3.6	4.3	0.7	1.5	2.6
Brizalina	0.3	0.3		0.3		0.6	1.5		1.0		1.0	0.3	0.3
Buccella	1.2	0.6					0.3	0.3	0.3	1.0	0.3		0.9
Bulimina	0.6	0.6	0.3			0.3	0.8	0.3	0.3		0.3	0.6	
Buliminella	0.9		0.3		0.3	0.3							
Cancris		0.9	0.7	0.6	0.3	1.3	1.3	0.7		0.3	1.7		0.3
Cassidulina	1.2								0.3		0.3	0.9	0.6
Cellanthus	3.6	5.0	4.6	5.2	4.1	4.9	7.2	5.0	1.6	3.0	2.7	2.7	3.1
Cibicidoides	6.3	0.6	0.3		1.2	1.3	2.6	3.0	5.2	3.0	5.3	5.5	7.4
Cornuspira	0.3	0.9	1.0	0.3	0.3	1.0	1.5	0.7					
Dentalina													0.3
Elphidium	2.4	6.9	7.9	7.7	4.6	7.1	3.6	3.3	5.2	4.3	5.6	3.0	2.8
Epistominella	0.6		0.7	0.9	0.6	0.6	1.0			0.3	0.3		
Eponides							0.5						
Euuvigerina	1.2								0.3			0.3	
Fissurina	0.6							0.7					
Florilus	2.4	2.8	3.6	5.2	2.0	3.2	4.4	2.3	2.3		3.3		0.3
Fursenkoina	1.5	0.3	0.3	0.9		0.3	0.5	0.7	0.7	0.3	0.3	0.3	
Gaudryina									0.7	0.3		0.3	0.9
Globocassidulina	3.0	0.3	1.0		0.3	0.3	1.8	0.3	1.0	0.3	1.3	0.9	0.6

Table C-2 (Continued).

Genus	Depth in Core (cm)												
	0	40	80	120	155	200	237	273	309	330	360	400	440
Hanzawia	1.2	0.3	0.7		0.6		2.1	1.0	0.3	2.3	1.7	0.9	0.9
Homotrema						0.3	0.3	0.3					
Leibusella												1.2	
Lenticulina	0.6			0.3		0.3			0.3				
Loxostomum	0.3						0.3			0.3	1.0	0.3	0.3
Melonis							0.8	0.3	0.3	0.3	0.3	0.9	
Miliolinella	3.6	1.6	3.6	4.9	2.9	4.5	5.7	1.3	1.6	2.3	1.3	1.2	0.6
Neoconorbina		0.3		1.2	0.9		0.5		0.7				0.6
Neoeponides	0.3						0.3		0.3	0.3	0.7	0.3	0.3
Nodobaculariella	0.3					0.3	0.8		1.6	3.0	1.0	2.7	2.6
Nonionella	0.6	2.5	3.0	2.1	2.6	1.9	5.4	2.3	1.0				0.3
Oolina	0.6												
Patellina	0.3			0.6	0.3		0.3	0.7	0.3				
Pavonina					0.6							0.3	
Peneroplis								1.0	0.7		1.0	0.9	1.1
Planorbulina	2.7	3.5	3.0	4.0	2.6	4.5	2.3	2.3	1.6	1.3	2.0	3.0	1.4
Planulina	3.3	10.7	9.2	7.7	10.7	9.7	5.4	6.0	6.9	5.6	8.3	4.3	6.0
Poroeponides	0.9	3.1	3.3	4.3	7.5	2.9	1.3	5.3	1.6	1.0	0.7	2.1	0.9
Protelphidium	0.9	2.5	5.3	0.6	2.6	1.9	2.6	1.7	1.0	0.7	1.7	0.9	
Pyrgo	0.6	1.6	2.6	4.0	4.6	2.9	3.6	2.0	0.3	2.3	0.3	1.5	0.9
Quinqueloculina	7.4	10.4	8.6	8.3	9.6	6.1	5.4	4.0	6.2	8.0	6.3	7.3	8.2
Rectobolivina	0.3	0.6	0.3	1.2		0.6	0.3	0.3		0.3	0.7	0.3	0.3
Reussella	1.8	2.8	3.0	1.5	1.4	2.3	2.8	1.7	5.9	4.7	3.3	5.5	6.3
Rosalina	9.5	17.3	19.1	12.6	7.2	12.3	8.7	6.3	9.2	5.6	10.0	8.8	2.6
Sagrina							1.0						0.3

Table C-2 (Continued).

Genus	Depth in Core (cm)												
	0	40	80	120	155	200	237	273	309	330	360	400	440
Sigmoilina	0.3			0.3		0.6	0.5		1.0	0.3			0.6
Sigmoilopsis	0.3	0.6		0.3	0.9	1.0		0.7	0.3	0.7			0.6
Siphonina	1.5			0.6	0.6	0.3	0.5	0.7	0.7	1.3	0.7	1.8	0.6
Spirillina	0.6						0.3				1.0		
Spiroloculina	0.3	0.9	1.6	0.9	0.3	1.0	1.3	0.7	3.3	0.7	0.7	0.9	1.1
Stromatorbina					0.3								0.3
Textularia	2.1	6.0	3.9	4.3	5.5	8.1	6.2	10.3	3.6	7.3	4.7	4.3	2.8
Textulariella								0.7	0.7	0.7			0.6
Trifarina	2.4	0.3	0.7	0.3	0.3	1.0	0.8	0.3	0.7		2.0	0.9	0.3
Triloculina	0.6	4.4	1.3	2.8	3.2	3.9	1.3	2.3	1.0	1.7	1.0	0.6	3.4
Genus X	0.9		1.0	1.2		0.6	0.5		1.0			1.2	
Genus Y	0.6	0.3		0.3									
Unidentified agglutinated forms					0.3					2.3			0.3
Unidentified miliolids		1.6	1.3		1.2	1.9	2.8	1.3		0.3	0.7	1.2	1.4
Other unidentified benthonics	1.2	0.3		1.5	1.4		0.8	1.0	0.7	1.3		0.6	
Total plantonics	24.1	2.8	3.6	6.1	4.1	4.5	4.9	2.3	7.2	9.6	11.3	10.9	10.5
Plantonic-benthonic ratio	0.32	0.03	0.04	0.07	0.04	0.05	0.05	0.02	0.07	0.11	0.13	0.12	0.12

Table C-3: Faunal composition of Core 8 (in percent).

Genus	Depth in Core (cm)										
	0	60	100	140	200	252	300	346	388	400	433
Ammonia			1.6		0.3	0.3		0.3		17.5	43.5
Amphistegina	5.5	14.8	3.3	6.9	18.1	7.1	5.3	5.9	7.1	2.6	
Amphorina	1.2									0.3	
Archaias			0.7	1.0	0.3		1.0	0.3	1.9	1.0	
Articulina		1.2	2.0	3.6	11.3	4.2	5.9	6.2	7.3	3.0	2.2
Bigenerina		0.3	0.3	1.0	0.6	0.3	1.0	0.7	1.6		
Brizalina	1.8	0.6	0.7	0.3		1.6	1.7	0.7	0.8	1.0	2.2
Buccella				0.3					0.3		
Bulimina	0.3					0.3			0.3	1.0	
Buliminella			0.3							6.3	
Cancris			0.3	1.6	0.3	1.0			0.3	0.3	2.2
Cassidulina	6.1	5.5	0.3								2.2
Cellanthus		0.3	3.6	3.9	1.0	1.6	0.7	1.0	1.4	1.3	
Cibicidoides	6.1	5.5	2.0	1.3	0.3	3.5	2.6	1.0	2.2	1.7	
Cornuspira	0.3	0.6	0.3	0.3	0.3	0.6	0.7	0.3			
Dentalina			0.3							0.3	
Ellipsocristellaria		0.3									
Elphidium	0.6	0.9	4.6	3.9	1.3	2.9	2.0	2.6	6.0	3.6	2.2
Epistominella	0.3			0.3				0.3	1.1	22.2	
Euuvigerina		0.9					0.3		0.5	0.3	2.2
Florilus		0.9	1.6		1.3	1.3	3.3	1.0		0.3	
Fursenkoina			1.0	0.3	0.3	0.6				1.7	
Gaudryina	1.2	0.3				0.3					2.2
Globocassidulina	6.1	4.3	0.7		1.0	3.5	1.3	0.3	0.5	1.0	
Gypsina	0.3										

Table C-3 (Continued).

Genus	Depth in Core (cm)										
	0	60	100	140	200	252	300	346	388	400	433
Hanzawia	0.3	0.3	0.3	0.7			0.3	2.9	1.1	0.7	
Homotrema	0.3	0.3	0.3								
Lenticulina		0.3								0.7	
Loxostomum	0.6	0.6				0.3	0.3	0.3	0.3	0.3	
Melonis								0.3		0.3	
Miliolinella	3.7	0.6	3.9	4.3	3.0	3.5	3.6	3.6	2.2	2.6	2.2
Neoconorbina			0.7		2.7				0.3		
Neoeponides		0.3									
Nodobaculariella		0.3	0.7	1.3	1.6	1.3	2.3	0.7	1.9	0.3	
Nonionella		0.3	1.3	1.6	0.3				0.3		
Oolina	0.3										
Patellina		0.3	0.3	0.3			0.3			0.3	
Pavonina	0.3	0.3						0.3			
Peneroplis				2.0	0.6	0.3	2.0	0.3	0.3		
Planorbulina	0.9		3.0	0.7	1.3	2.3	2.0	4.6	3.3	2.0	
Planulina	1.2	4.3	9.2	14.4	4.5	8.4	8.6	10.7	8.7	2.3	6.5
Poroeponides		0.6	1.3	1.0	0.3	0.3	0.7	1.3	0.5		
Protelphidium	0.6	0.9	1.6	1.0	1.3	1.0	1.7	1.6	2.2	1.0	
Pullenia	0.3	0.3				0.3					
Pyrgo	0.3	0.9	2.3	1.6	0.6	0.6	1.7	2.0	1.4		
Quinqueloculina	2.7	4.3	7.5	9.5	8.1	7.1	7.9	10.4	7.9	5.3	4.3
Rectobolivina				1.6		0.6	0.3	0.3	0.5		
Reussella	3.0	2.2	1.6	3.9	2.3	2.3	2.0	2.0	4.6	0.7	
Rosalina	1.5	4.6	18.7	13.1	14.9	10.3	10.2	14.7	12.0	4.3	
Sagrina				0.3	1.0		0.3	0.3	1.1		

Table C-3 (Continued).

Genus	Depth in Core (cm)										
	0	60	100	140	200	252	300	346	388	400	433
Sarcenaria	0.3										
Sigmoilina	0.3								0.8		
Sigmoilopsis		0.3							0.3	0.7	
Siphonina	0.3	2.1			0.3	0.6	2.0		1.6	0.3	
Sphaeroidina											2.2
Spiroloculina	0.3	1.9	1.3	1.6	4.0	2.6	4.6	3.7	1.9	1.0	
Textularia	1.8	1.5	6.2	2.6	1.7	0.3	0.7	0.7	1.4	1.7	4.3
Textulariella					0.3						
Tretomphalus		0.3			1.3	0.3	1.0	0.7	1.4		
Trifarina	0.9	0.3	1.0	0.3	0.3	1.3	1.3	0.7	1.4	0.3	
Triloculina	0.6	0.6	2.3	1.6	2.0	3.2	4.3	3.3	1.1	1.1	2.2
Vaginulinopsis	0.3										
Genux X	0.3	0.3		0.3	2.0	0.6			0.5		
Genus Y			1.0				0.3			0.3	
Unidentified agglutinated forms		0.6		0.3					0.3	2.0	2.2
Unidentified miliolids	0.3	0.6	0.7	2.0	0.6	1.6	1.3	4.2	2.4		2.2
Other unidentified benthonics	1.5	1.9	2.3	1.3	1.6	1.3		1.0	0.5	1.3	13.0
Total planktonics	45.9	30.3	7.2	6.6	7.1	18.0	13.2	7.8	6.8	3.3	2.2
Planktonic-benthonic ratio	0.85	0.44	0.08	0.07	0.08	0.22	0.15	0.09	0.07	0.03	0.02

Table C-4: Faunal composition of Cores 27 and 29 (in percent).

Genus	Core 27 Depth in Core (cm)					Core 29 Depth in Core (cm)	
	0	50	110	150	190	0	40
Ammonia					0.7		1.2
Amphistegina	4.4	13.3	15.6	11.1	11.7	24.5	0.6
Amphorina		0.3					
Articulina		1.0	2.7	2.5	1.3	2.0	0.3
Bigenerina		0.7		0.3		0.3	2.1
Brizalina	1.1		1.7	0.6	1.3	0.7	3.7
Buccella		0.3					
Bulimina							1.5
Cancris			0.7	0.3	0.3	0.3	0.6
Cassidulina	4.2	4.9	2.7			10.1	
Cellanthus				0.3			1.8
Cibicidoides	3.9	4.5	4.2	5.4	6.2	4.9	8.2
Cornuspira	0.3	1.3	0.7				0.3
Ellipsocristellaria						0.3	
Elphidium	0.3		1.0		0.7		0.6
Epistominella					0.3		2.4
Eponides						0.3	0.3
Euuvigerina			0.7		0.3	0.7	1.5
Florilus				0.3			0.3
Fursenkoina			0.6	0.3			

Table C-4 (Continued).

Genus	Core 27 Depth in Core (cm)					Core 29 Depth in Core (cm)	
	0	50	110	150	190	0	40
Globocassidulina	3.1	2.3	0.3	1.3	1.0	4.2	1.2
Gypsina		0.7					
Hanzawia	0.3				0.7	0.3	3.4
Homotrema	0.6	0.3					
Lenticulina	0.6			0.3		1.0	3.4
Loxostomum		0.7		0.3		0.7	0.3
Marginulinopsis							0.9
Melonis	0.6	1.3	0.3	0.6	0.3		
Miliolinella	1.1	1.3	2.0	0.9	2.0	0.3	
Neoeponides						0.3	
Nodobaculariella		0.3	1.0				
Nonionella						0.3	0.3
Patellina	0.6	0.3		0.6		1.0	0.3
Peneroplis				0.6	1.0	0.3	
Planorbulina	2.8			0.3		0.7	0.3
Planulina	2.8	5.5	6.0	7.0	2.9	1.0	0.9
Poroeponides	1.1	1.0	1.3	0.9	1.0	0.3	
Protelphidium		0.3	0.3		1.0		
Pyrgo		0.7		1.3	0.7	0.3	
Quinqueloculina	5.8	3.2	6.3	8.9	6.8	2.6	5.8

Table C-4 (Continued).

Genus	Core 27					Core 29	
	Depth in Core (cm)					Depth in Core (cm)	
	0	50	110	150	190	0	40
Rectobolivina					0.7		
Reussella	2.2	1.0	2.0	1.9	0.7	1.6	1.2
Rosalina	5.6	3.9	7.3	8.5	5.2	1.0	1.5
Sagrina	0.3		0.3				0.6
Sigmoilina		0.3					
Sigmoilopsis				0.3	0.3	0.7	3.4
Siphonina		1.9	0.7	1.6	2.3	1.0	1.5
Spirillina	3.1	3.9	3.3	2.8	1.0		0.3
Spiroloculina	1.7	1.0	2.0	2.2	1.3	0.3	0.3
Textularia	0.6		2.0	1.9	1.0	1.0	1.2
Tretomphalus		0.3		2.2	0.7		
Trifarina	0.6	0.7	0.7	1.3	1.0	0.3	
Triloculina	0.8	0.7	2.0	2.2	2.0	0.3	
Tritaxia							1.2
Vaginulina						1.3	
Vaginulinopsis			1.0				
Genus X		1.0			1.3	0.7	0.9
Genus Y		1.0					

Table C-4 (Continued).

Genus	Core 27					Core 29	
	Depth in Core (cm)					Depth in Core (cm)	
	0	50	110	150	190	0	40
Unidentified agglutinated forms							4.0
Unidentified miliolids	0.3	0.7	1.3	1.6	1.0	0.3	
Other unidentified benthonics		4.9			1.6	0.3	3.0
Total planktonics	51.7	35.6	29.9	28.8	29.7	33.7	38.4
Planktonic-benthonic ratio	1.07	0.55	0.43	0.40	0.66	0.51	0.62

Table C-5: Faunal composition of cores 42 and 24 (in percent).

Genus	Core 42 Depth in Core (cm)							Core 24 Depth in Core (cm)		
	0	60	100	143	170	200	240	0	35	70
Ammonia						0.3	24.0			
Amphicoryna										0.3
Amphistegina	6.0	7.5	12.4	3.0	4.5	0.6		10.6	48.4	21.1
Amphorina								0.3		
Archaias	4.3	0.8	7.3	3.8	4.8	0.9				
Articulina	9.9	5.7	10.2	6.5	7.1	8.4	2.5			1.6
Biarritzina									0.3	
Bigenerina	0.7	0.5	0.3		0.6	1.5			1.0	0.3
Brizalina	0.3	1.8	0.3	1.4	0.6	1.2	12.5	0.7	0.3	0.7
Buccella		0.8	1.1	0.3		0.6				0.3
Bulimina	0.3			0.5			0.9		0.3	
Buliminella							2.5			
Cancris	0.7	0.3		0.5	0.8	0.3		0.3		0.3
Cassidulina		0.3			0.3			12.9	1.6	4.9
Cellanthus	3.3	1.1	2.2	4.6	1.7	8.4	0.9			
Cibicidoides	4.3	2.9	3.0	3.3	0.8	1.2	0.9	4.6	1.6	7.2
Cornuspira	0.3	0.3	0.3	0.5	0.6				0.3	
Elphidium	3.3	1.1	3.8	3.3	4.5	4.4	4.4	0.7	0.3	0.7
Epistominella	0.7		0.3	0.5	0.6	1.2	17.4			0.7
Eponides	0.3				0.3					

Table C-5 (Continued).

Genus	Core 42							Core 24		
	Depth in Core (cm)							Depth in Core (cm)		
	0	60	100	143	170	200	240	0	35	70
Euuvigerina	0.3		0.3	0.8			4.0	0.3		0.3
Florilus		1.1	1.1	0.8	1.1	3.5	0.3			0.7
Fursenkoina	0.3	0.8	0.5	0.3	0.3	0.6	4.4			0.3
Gaudryina								1.0	2.2	0.7
Globocassidulina	3.0	1.1	1.1	6.0	1.1	3.8	1.9	6.3	0.6	4.9
Gypsina								0.7		1.0
Hanzawia	1.3	0.3	0.5	0.3	1.1	2.9	0.9		0.6	
Homotrema									0.3	0.3
Lenticulina							1.6	0.3	0.3	
Loxostomum	0.7	0.3	0.5	0.8	1.1	1.2				
Melonis				0.3	0.6					0.3
Miliolinella	3.6	4.8	3.0	3.5	0.8	2.6	0.3	1.7		2.0
Neoconorbina		3.5	0.3							0.3
Neoeponides		0.3							0.3	
Nodobaculariella	1.0	0.8	2.4	0.8	2.5	3.2	0.6		1.0	
Nonionella	0.7	0.5	0.5	0.8	0.6	1.5	3.7			
Oolina								0.3		0.3
Patellina	0.3	0.8	0.3	0.3	0.6				0.3	
Pavonina			0.3			0.3				
Peneroplis	2.0		3.2	1.1	2.5	0.9	0.3			0.3

Table C-5 (Continued).

Genus	Core 42 Depth in Core (cm)							Core 24 Depth in Core (cm)		
	0	60	100	143	170	200	240	0	35	70
Planorbulina	0.3	1.3	1.9	1.6	2.5	2.3		0.3		
Planulina	3.6	4.8	2.7	3.5	4.8	6.7	0.9	1.7	0.3	3.0
Poroeponides	0.3	0.8	0.5	1.1	0.3	0.6		0.7	3.8	1.3
Protelphidium	2.3	0.8	0.5	0.8	2.3	2.6	0.6	0.3		
Pyrgo		0.8	0.8	0.5	0.6	1.2		1.3	1.3	0.3
Quinqueloculina	6.0	9.9	8.6	6.2	9.3	3.5	1.9	0.7	2.6	2.0
Rectobolivina		1.3	1.1		0.3	1.5	0.3			0.3
Reussella	3.0	1.6	1.9	3.0	2.8	3.5	0.9	3.0	1.9	2.0
Rosalina	8.3	19.7	9.7	9.5	12.2	7.8	2.8	3.3	0.3	4.3
Sagrina	1.0	0.3		0.8	0.6	1.5	0.6			
Sarcenaria						0.3	1.6	0.3	0.3	
Sigmoilina		0.3	0.3		0.3					0.3
Sigmoilopsis	0.3		0.8	0.5				0.3	0.6	
Siphonina	0.7	0.3		0.3	0.6	0.9	0.3	0.7	0.6	1.0
Siphotextularia		0.3								
Spirillina	1.0	0.5	0.3	0.3	0.3	0.6	0.6		0.3	2.0
Spiroloculina	1.0	3.7	1.9	1.4	1.4	2.0				
Sporatotrema									0.3	
Stromatorbina			0.3					0.3	0.6	
Textularia	2.3	1.9	1.9	3.0	2.0	2.0		1.7	0.6	1.0

Table C-5 (Continued).

Genus	Core 42							Core 24		
	Depth in Core (cm)							Depth in Core (cm)		
	0	60	100	143	170	200	240	0	35	70
Textulariella	0.3		0.3			0.3				0.3
Tretomphalus			0.3	0.3						
Trifarina	1.0			1.1	1.7	1.7	0.6		0.3	0.7
Triloculina	1.7	2.7	1.1	1.9	2.3	2.0	0.3	0.7	0.6	2.0
Trochammina								0.3		
Vaginulinopsis									0.3	
Vaginulina								0.3		
Genus X	2.3		0.8	1.9	1.4	2.9	0.6	0.7		0.3
Genus Y								0.7		0.3
Unidentified agglutinated forms	0.3			0.3				0.7	2.9	1.0
Unidentified miliolids	1.3	2.9	0.8	2.2	2.0	0.9	0.6	0.7	0.3	2.0
Other unidentified benthonics	3.0	2.0	0.3	0.9		1.7	0.6	4.6	1.3	3.6
Total planktonics	11.9	8.0	8.4	15.2	13.3	4.1	2.2	35.4	20.5	21.7
Planktonic-benthonic ratio	0.13	0.09	0.09	0.18	0.15	0.04	0.02	0.55	0.26	0.27

Table C-6: Faunal composition of Core 22 (in percent).

Genus	Depth in Core (cm)												
	0	60	100	140	165	200	240	280	320	360	400	460	514
Ammonia			0.5			0.3				0.5	0.2		1.0
Amphistegina		1.0	0.5	0.5	0.5	1.0	0.8	0.3	0.3			0.5	3.1
Archaias		0.3				0.8	0.8	0.3	0.3				
Articulina	0.3	2.3	3.5	4.6	5.9	6.5	5.7	6.1	4.9	2.3	0.2	1.6	2.1
Bigenerina	0.8	0.8		0.5		1.0	0.3	1.0	0.3	0.8	0.2		0.5
Brizalina	2.1	1.3	2.4	2.3	0.5	2.0	1.5	1.0	1.3	1.0	2.3	0.5	1.3
Buccella		0.8				0.8	0.3			0.8	0.7	0.5	0.5
Bulimina	0.5	0.3	1.6	0.5	0.5	0.3	0.3		0.8	0.5	1.2	0.9	0.5
Buliminella													0.3
Cancris	0.5	0.5	0.8			0.3	0.3		0.5	1.8	0.9	0.7	
Cassidulina		0.5								0.3			
Cellanthus	2.3	4.2	2.7	4.6	6.5	4.8	6.2	6.8	5.9	8.2	5.5	8.0	2.6
Cibicidoides	13.1	3.9	2.7	3.3	2.4	3.3	3.3	5.5	5.7	5.4	2.8	2.5	2.6
Cornuspira			1.3	0.3	1.4	0.5	0.8	0.3	1.0	1.8	0.5	0.2	0.5
Elphidium	0.5	4.2	2.4	4.1	4.3	3.0	5.4	5.2	4.6	2.3	3.2	7.6	5.9
Epistominella		0.8	0.8	0.5	1.1	1.0	1.0		1.0	0.5	1.2	0.5	
Eponides				0.3						0.3			
Euuvigerina	7.2	1.6	0.5			0.8	1.5	0.6	0.5	2.3	0.9	0.2	0.8
Florilus		2.1	0.5	2.3	3.0	1.3	1.5	1.9	2.8	2.6	2.8	3.4	2.1
Fursenkoina	0.3	0.5	0.3	0.3	0.3	0.5	0.8	0.6		0.3	0.2	1.1	0.3
Gaudryina		0.5			0.3								
Globocassidulina		4.5	3.2	3.6	4.3	1.8	4.1	2.6	2.6	3.1	5.1	3.7	2.1
Hanzawia	1.8	1.3		1.5	0.3	1.3	1.3	1.3	1.6	1.8	0.7	1.6	1.3
Homotrema								0.6					
Lenticulina	0.5	0.3			0.5		0.8		0.3	0.3		0.5	

Table C-6 (Continued).

Genus	Depth in Core (cm)												
	0	60	100	140	165	200	240	280	320	360	400	460	514
Loxostomum	0.5	2.9	0.3	0.8	1.6	0.3	1.0	0.3	1.0	0.5	0.5	0.9	0.5
Marginulina										0.3			
Melonis	0.3	0.3	0.3	0.5		0.3	0.3	0.6	0.3	0.5			0.5
Miliolinella	0.3	3.4	5.4	4.1	1.4	2.3	3.3	3.6	3.6	4.1	3.9	2.3	
Neoconorbina			0.3										
Neoeponides		0.3											0.5
Nodobaculariella						0.5	0.5						0.3
Nonionella	0.3	1.6	0.3	2.1	0.5	1.8	1.5	1.3	1.3	1.8	2.1	0.9	
Oridorsalis							0.3						
Patellina		0.3	0.5	0.5	0.5	0.5		0.3	0.3		0.2		0.3
Pavonina			1.1	1.5	1.4	0.3		0.3	0.5	0.3	0.2		
Peneroplis		0.8	0.8	0.8	0.3	0.5		0.3	0.3			0.2	2.6
Planorbulina	1.0	1.3	3.8	2.6	0.8	2.5	3.3	1.6	0.5	2.3	2.3	3.4	2.6
Planulina	0.5	3.4	4.3	3.6	5.9	5.0	3.3	7.4	4.1	1.5	5.1	4.1	6.4
Poroeponides	0.5	0.3	0.3	0.8	0.3	0.8	0.8	1.3	0.5	0.3	0.2		0.2
Protelphidium		1.0	2.1	1.3	1.1	0.8	0.8	1.3	1.5	2.0	3.2	3.7	2.3
Pullenia	0.5	0.5							0.3				0.3
Pyrgo		0.5	1.3		1.1	1.3	0.8	1.0	2.3	1.0	0.5	0.7	0.3
Quinqueloculina	1.8	6.0	8.3	9.7	7.0	8.6	6.7	9.1	6.7	5.6	6.2	5.5	5.4
Rectobolivina		0.5		0.5	0.3	0.5	1.0				1.6	0.5	
Reussella	0.8	3.9	3.2	3.1	2.2	4.3	2.8	4.2	1.8	4.6	3.2	1.6	2.1
Rosalina	2.6	11.8	16.4	12.6	11.6	15.1	10.5	12.3	13.1	10.7	12.2	12.6	9.3
Sagrina		0.5	3.0	1.8	3.8	1.5	1.0	1.3	3.6	1.8	1.4	2.8	6.4
Sigmoilina	0.3			0.5	1.4	0.3	0.3	0.6	0.5	0.5	0.5	0.4	
Sigmoilopsis	1.0			0.8						0.3			

Table C-6 (Continued).

Genus	Depth in Core (cm)												
	0	60	100	140	165	200	240	280	320	360	400	460	514
Siphorina	1.0	1.3	0.3	0.5	0.8	0.3	1.0	1.0	1.5	0.5	1.6	0.5	2.1
Siphotextularia			0.3	0.3								0.2	
Sphaeroidina	0.8		0.3										
Spirillina		0.5	0.3		1.9	0.8	0.8	1.0	1.3	0.3		0.2	0.5
Spiroloculina	0.3	1.0	1.9	1.5	2.4	1.3	1.5	1.6	1.3	1.0	0.9		1.0
Textularia	2.3	2.1	0.8	0.8	1.1	1.8	1.8	2.9	3.6	6.3	7.1	3.4	1.5
Textulariella											0.2		
Tretomphalus			1.1	1.8	1.4		0.3	1.3	0.5				
Trifarina	0.5	1.0	0.5	0.5	1.9	1.3	0.8		0.5	0.3	0.9	1.4	2.1
Triloculina		1.0	2.7	1.3	1.4	2.5	2.8	1.9	4.1	0.5	2.1	0.9	1.3
Tritaxia	0.3												
Vaginulinopsis	0.5								0.3				
Genus X	0.3	1.6	1.6	2.8	3.0	1.5	1.3	2.3	1.5	3.8	1.4	0.5	0.5
Genus Y			0.5	0.3	0.3				0.3				
Unidentified agglutinated forms	0.8	0.3		1.0									
Unidentified miliolids	0.5	1.8	3.0		3.2	2.3	0.8	1.0	1.3	0.8	0.5	1.4	0.5
Other unidentified benthonics	0.5	2.1	1.3	3.6	0.5	0.3	1.8	0.3	0.8	1.0	1.2	0.9	2.6
Total planktonics	52.6	16.0	9.9	8.7	9.7	10.3	12.3	4.9	6.7	10.7	11.9	16.3	20.6
Planktonic-benthonic ratio	1.11	0.19	0.11	0.10	0.11	0.12	0.14	0.05	0.07	0.12	0.14	0.20	0.26

APPENDIX D

SIGNIFICANT FAUNAL VARIATIONS

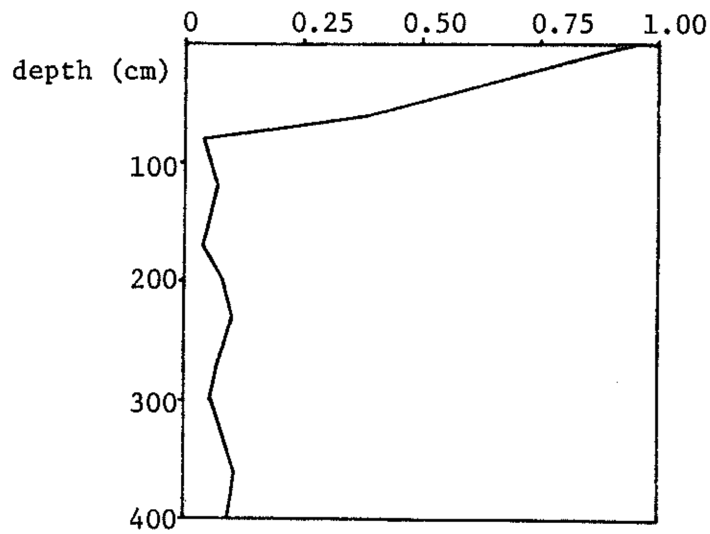


Fig. D-1-Fluctuations in the planktonic-benthonic ratio with depth in Core 37.

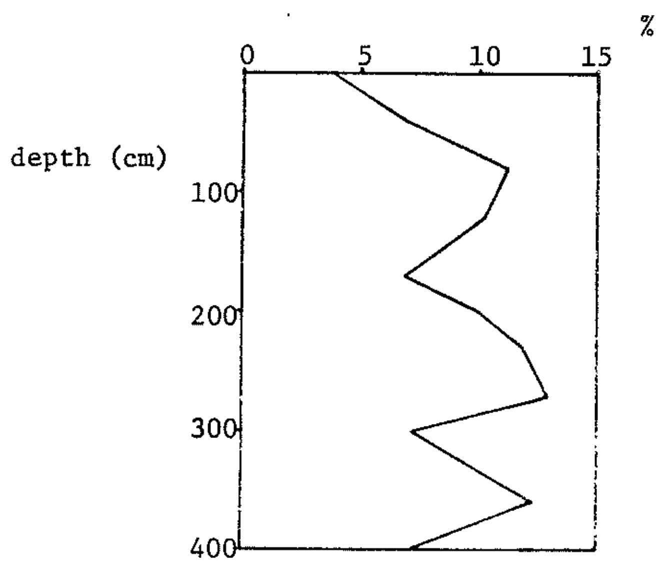


Fig. D-2-Fluctuations in the relative abundance of Rosalina with depth in Core 37.

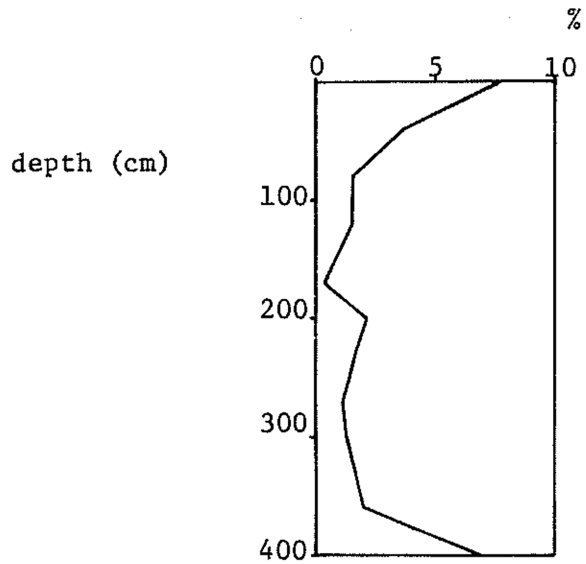


Fig. D-3-Fluctuations in the relative abundance of Cibicidoides with depth in Core 37.

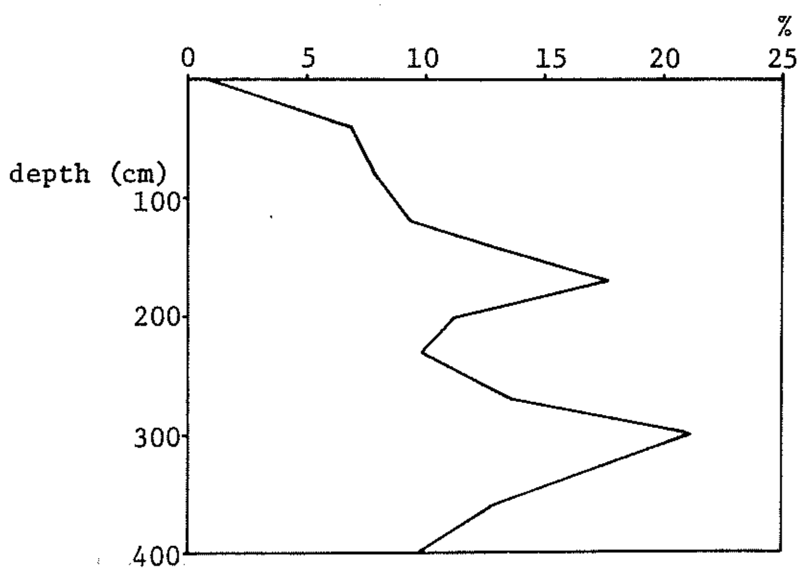


Fig. D-4-Fluctuations in the relative abundance of Nonionella with depth in Core 37.

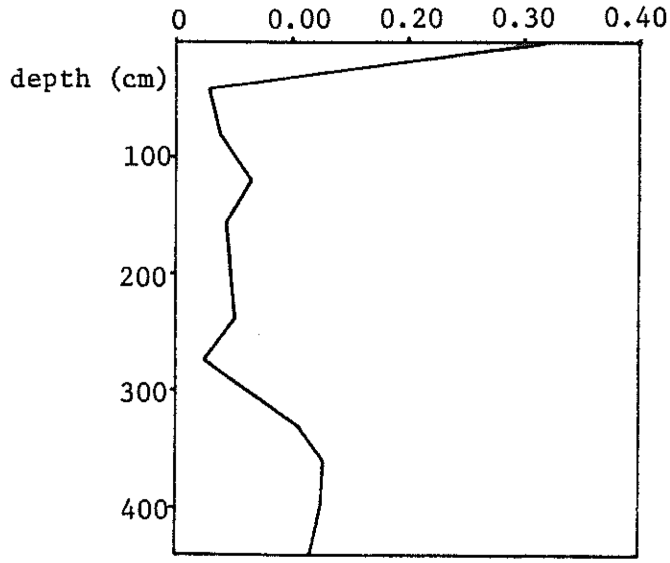


Fig. D-5-Fluctuations in the plantonic-benthonic ratio with depth in Core 40.

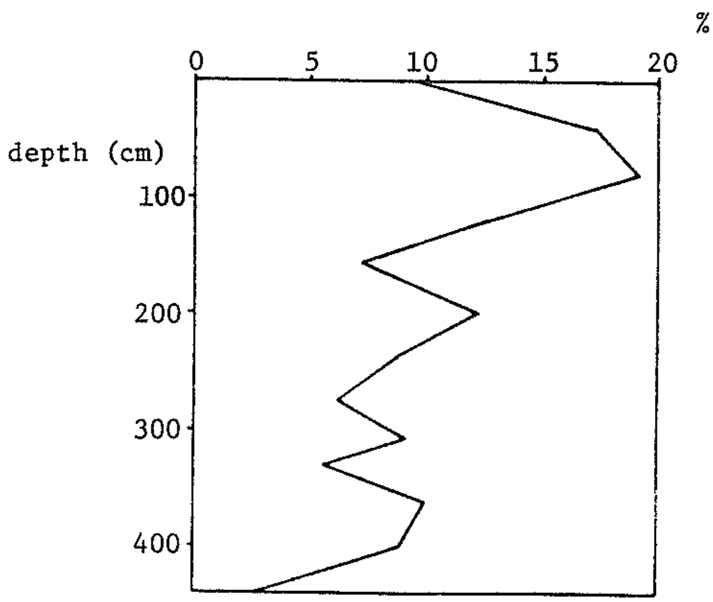


Fig. D-6-Fluctuations in the relative abundance of Rosalina with depth in Core 40.

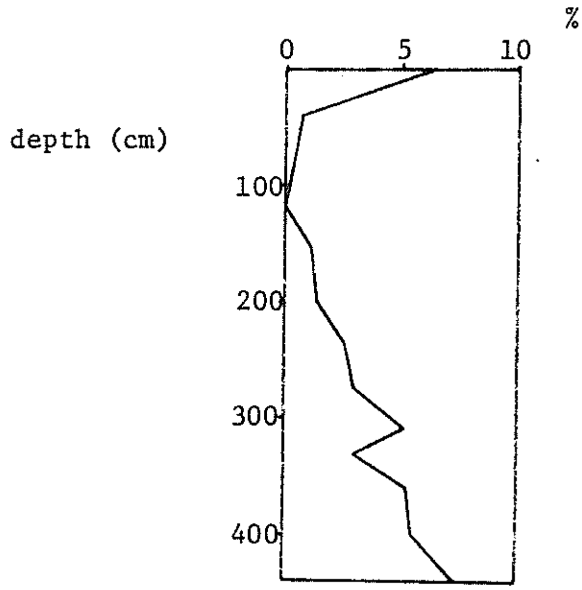


Fig. D-7-Fluctuations in the relative abundance of Cibicidoides with depth in Core 40.

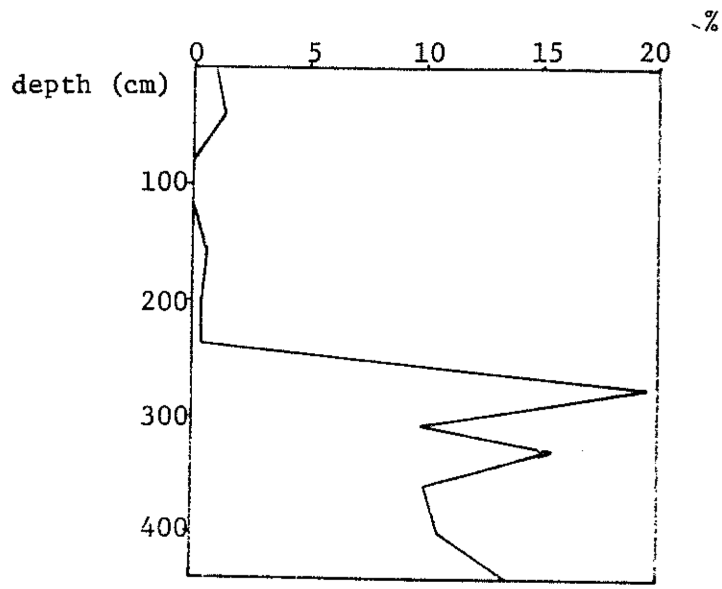


Fig. D-8-Fluctuations in the relative abundance of Amphistegina with depth in Core 40.

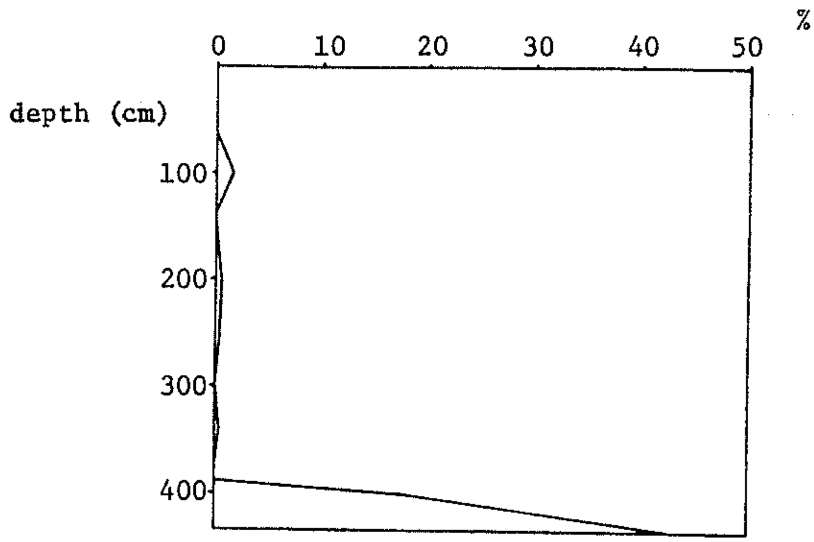


Fig. D-9-Fluctuations in the relative abundance of <u>Ammonia</u> with depth in Core 8.

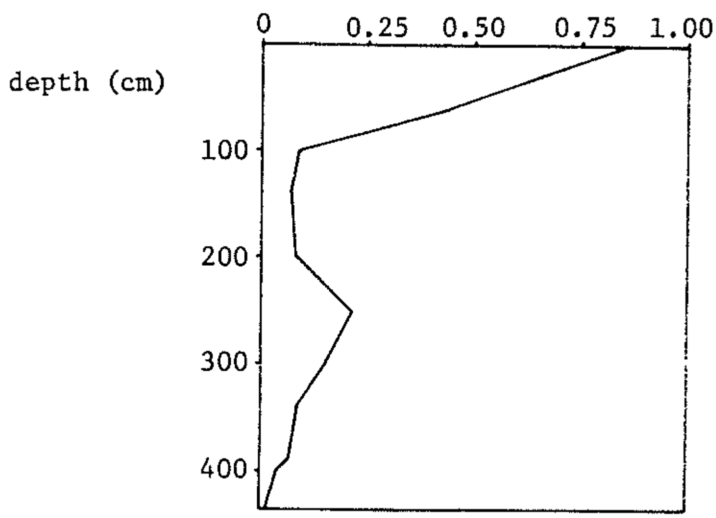


Fig. D-10-Fluctuations in the planktonic-benthonic ratio with depth in Core 8.

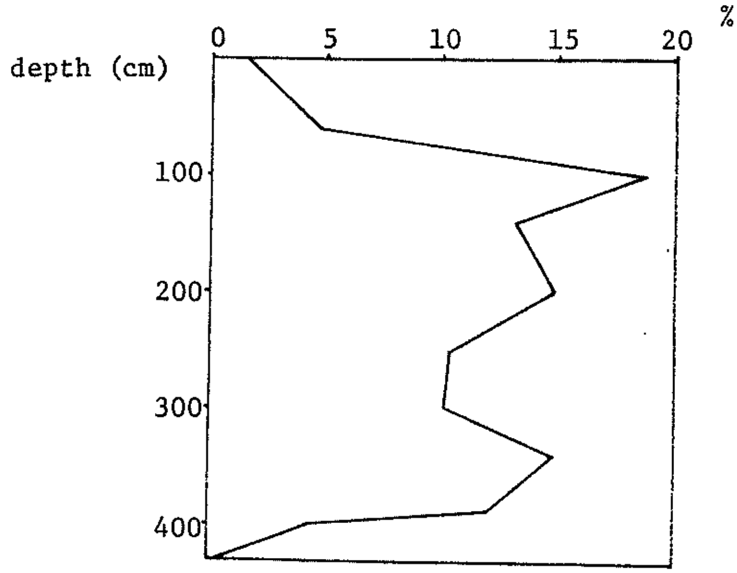


Fig. D-11-Fluctuations in the relative abundance of <u>Rosalina</u> with depth in Core 8.

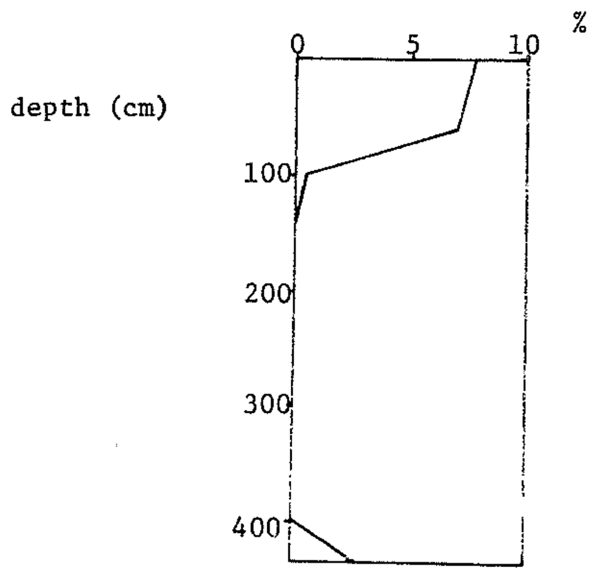


Fig. D-12-Fluctuations in the relative abundance of <u>Cassidulina</u> with depth in Core 8.

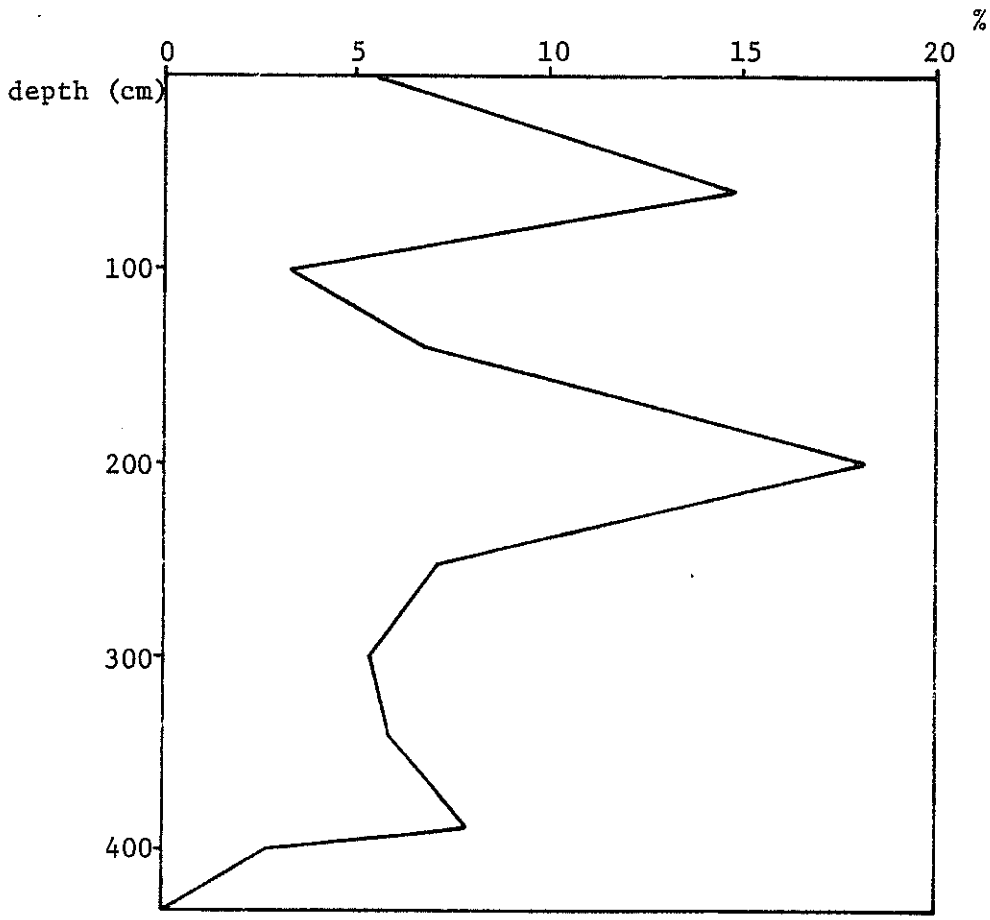


Fig. D-13-Fluctuations in the relative abundance of _Amphistegina_ with depth in Core 8.

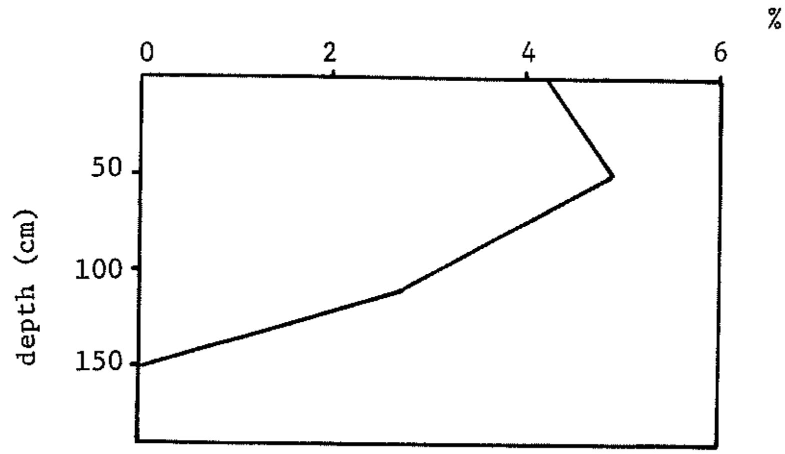


Fig. D-14-Fluctuations in the relative abundance of Cassidulina with depth in Core 27.

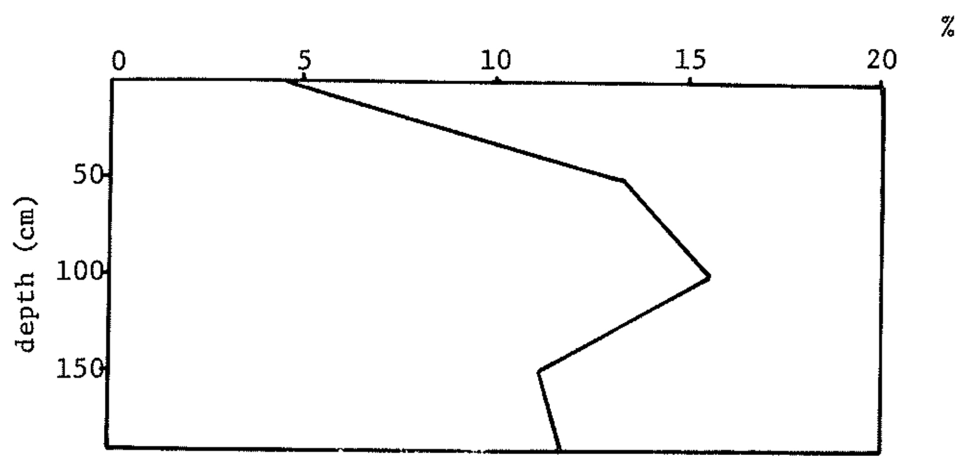


Fig. D-15-Fluctuations in the relative abundance of Amphistegina with depth in Core 27.

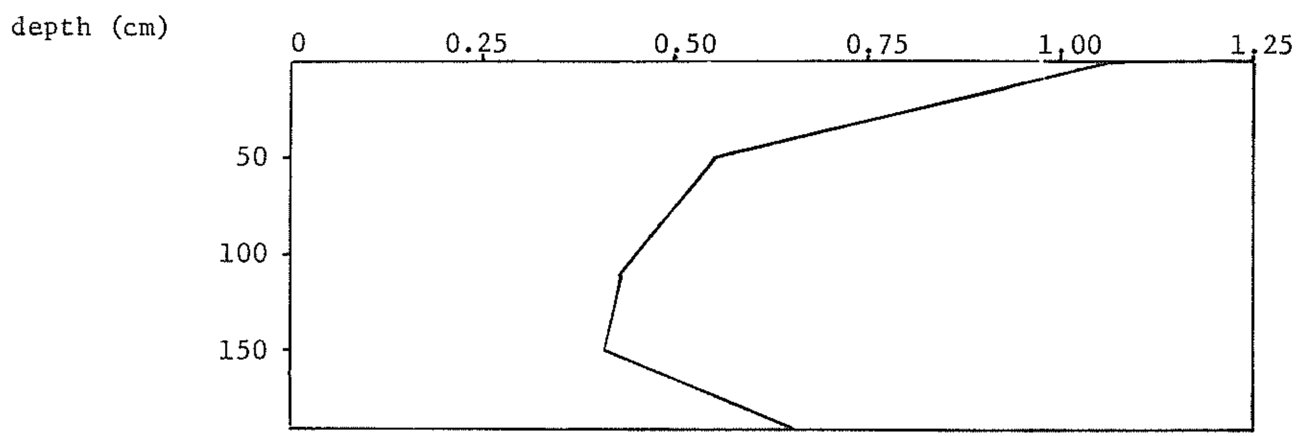


Fig. D-16-Fluctuations in the planktonic-benthonic ratio with depth in Core 27

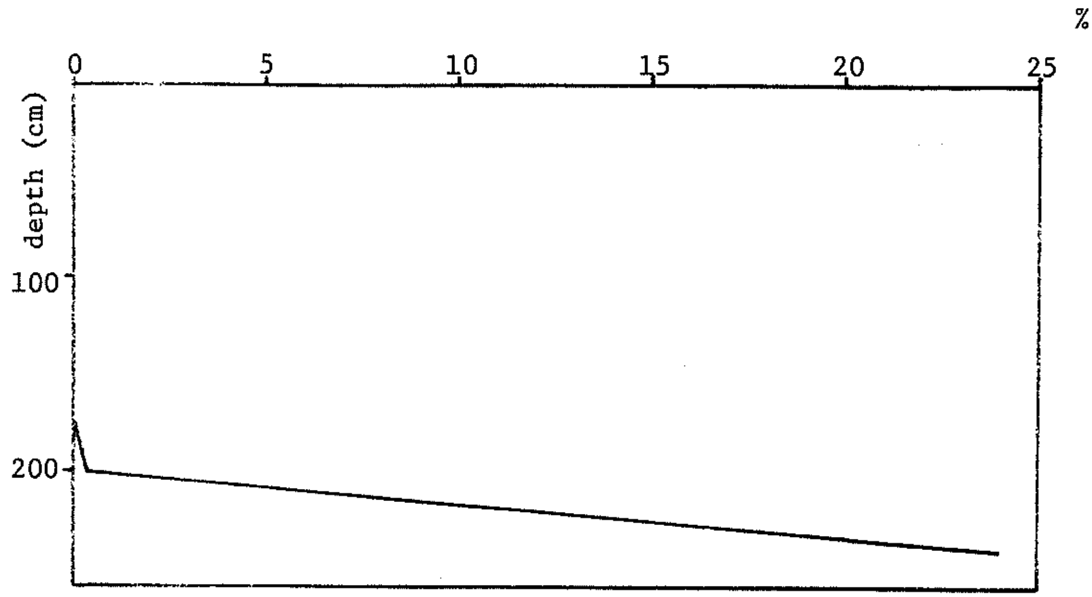


Fig. D-17-Fluctuations in the relative abundance of Ammonia with depth in Core 42.

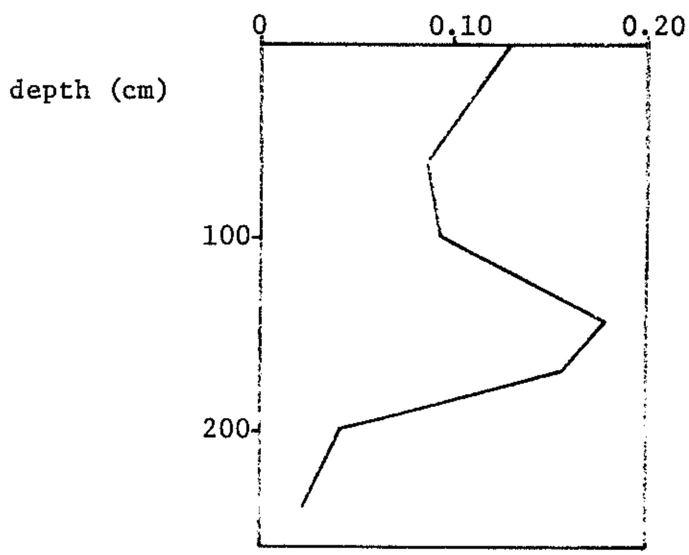


Fig. D-18-Fluctuations in the planktonic-benthonic ratio with depth in Core 42.

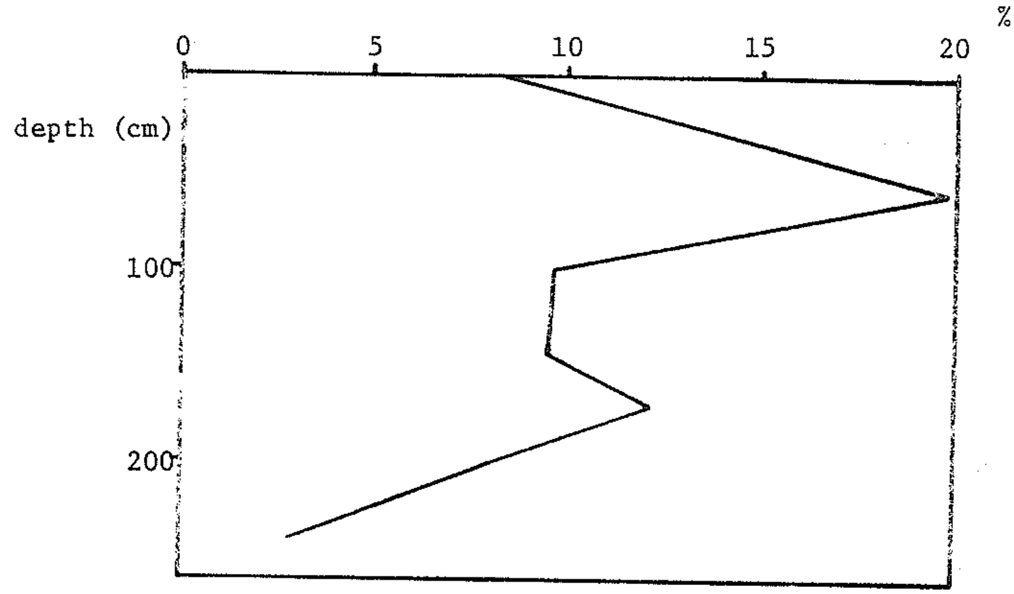


Fig. D-19-Fluctuations in the relative abundance of Rosalina with depth in Core 42.

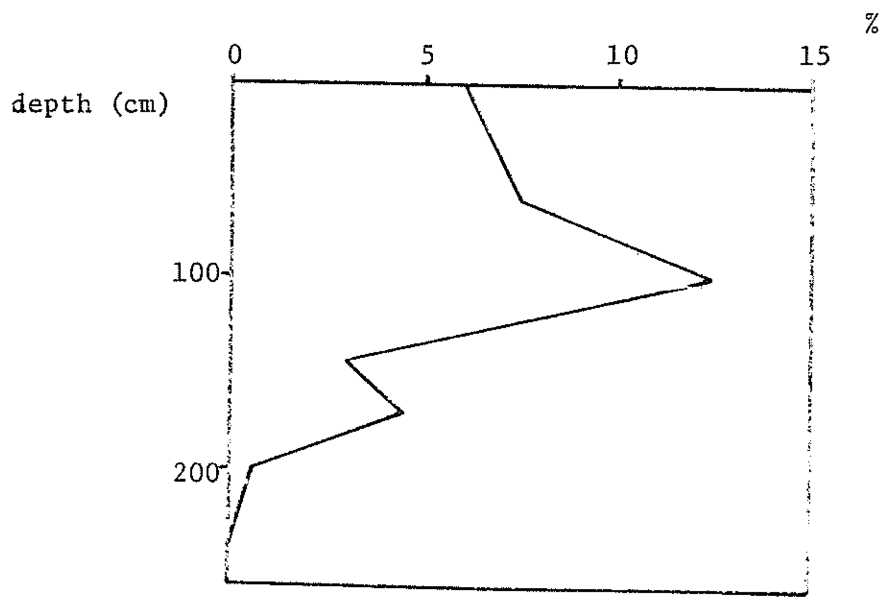


Fig. D-20-Fluctuations in the relative abundance of Amphistegina with depth in Core 42.

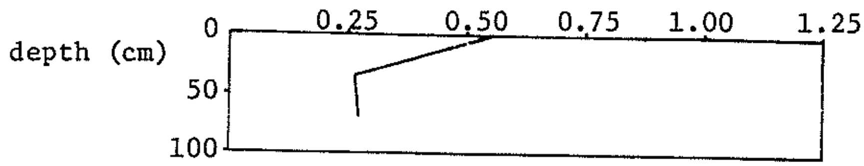


Fig. D-21-Fluctuations in the planktonic-benthonic ratio with depth in Core 24.

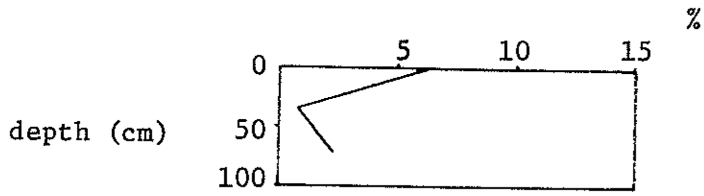


Fig. D-22-Fluctuations in the relative abundance of Cassidulina with depth in Core 24.

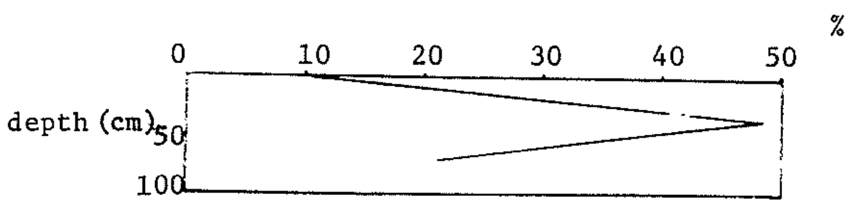


Fig. D-23-Fluctuations in the relative abundance of Amphistegina with depth in Core 24.

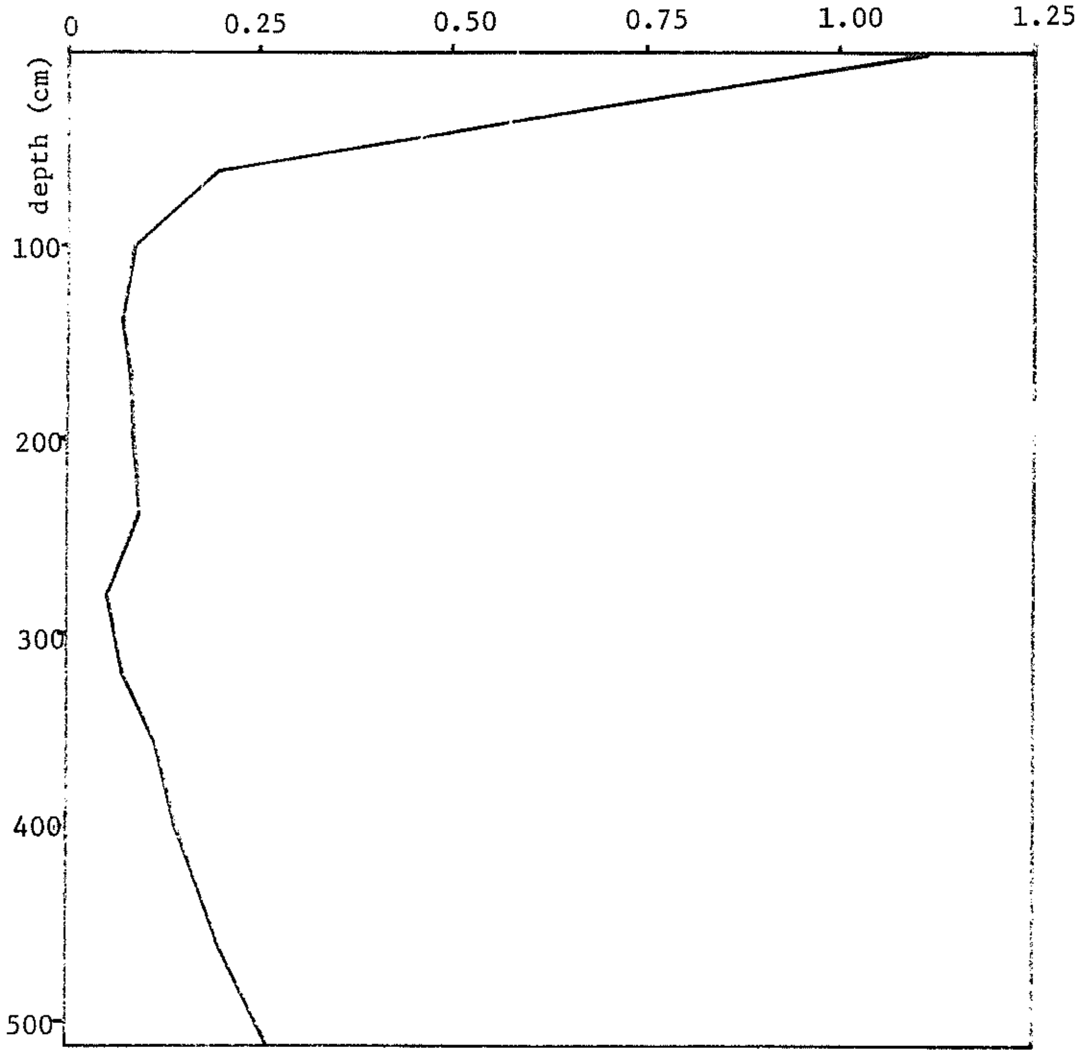


Fig. D-24-Fluctuations in the planktonic-benthonic ratio with depth in Core 22.

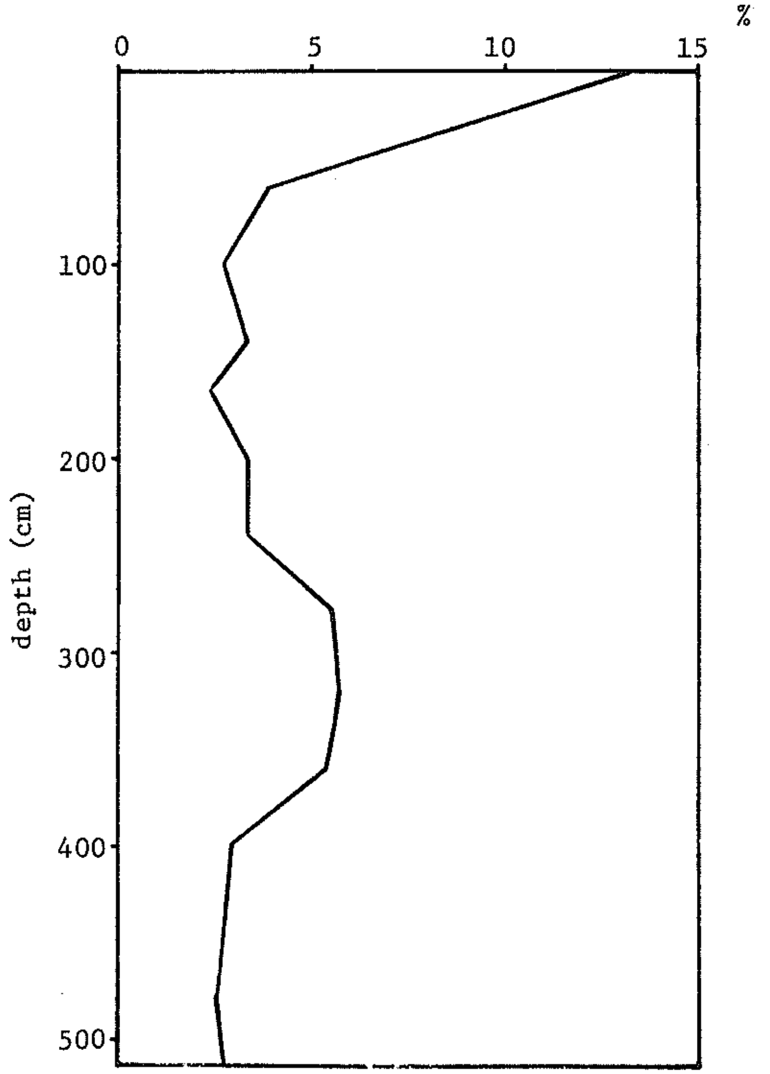


Fig. D-25-Fluctuations in the relative abundance of Cibicidoides with depth in Core 22.

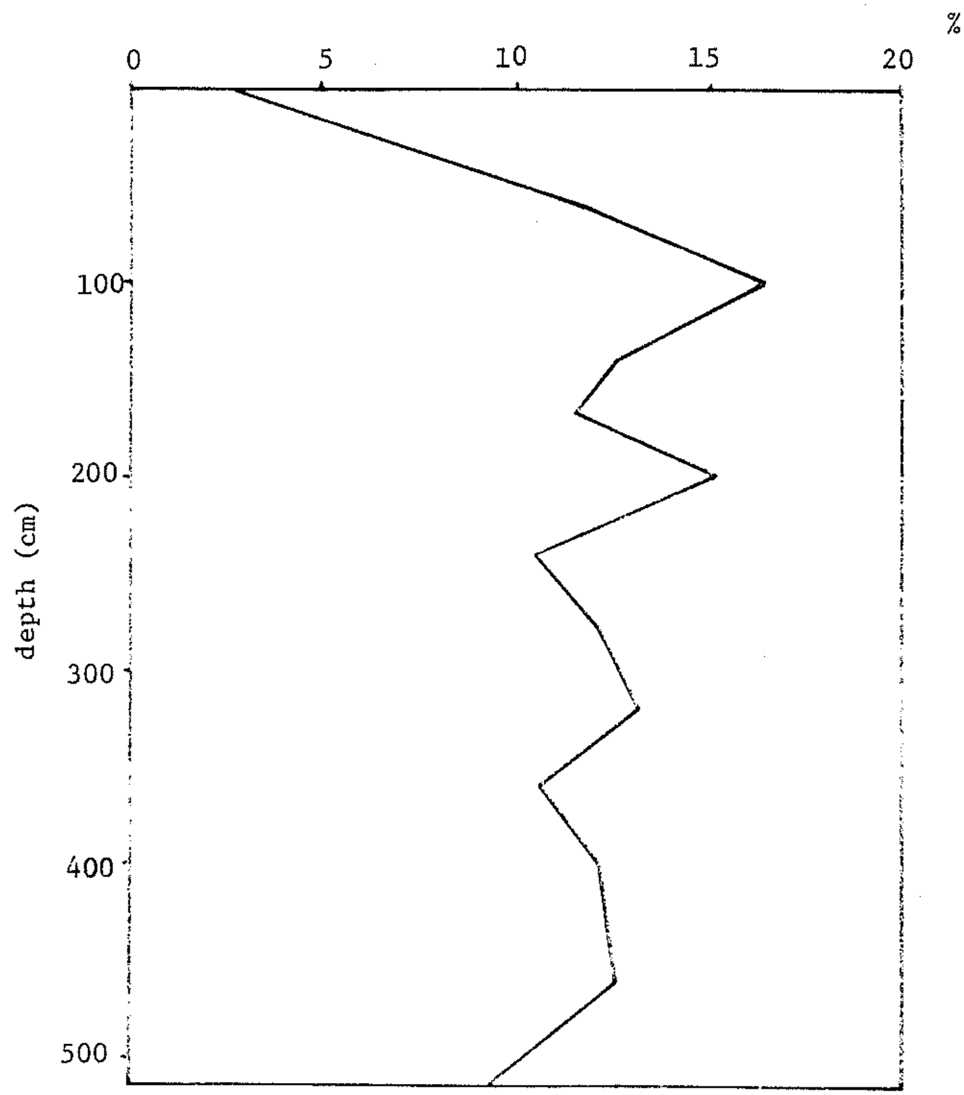


Fig. D-26-Fluctuations in the relative abundance of Rosalina with depth in Core 22.

APPENDIX E

SCANNING ELECTRON PHOTOMICROGRAPHS OF KEY BENTHONIC FORAMINIFERS

Plate 1

A. Epistominella vitrea Parker, umbilical view, Core 8, 400 cm, x390.

B. Epistominella vitrea Parker, spiral view, Core 8, 400 cm, x350.

C. Buliminella morgani Andersen, lateral view, Core 37, 200 cm, x290.

D. Nonionella opima Cushman, spiral view, Core 37, 170 cm, x250.

E. Nonionella opima Cushman, umbilical view, Core 37, 170 cm, x250.

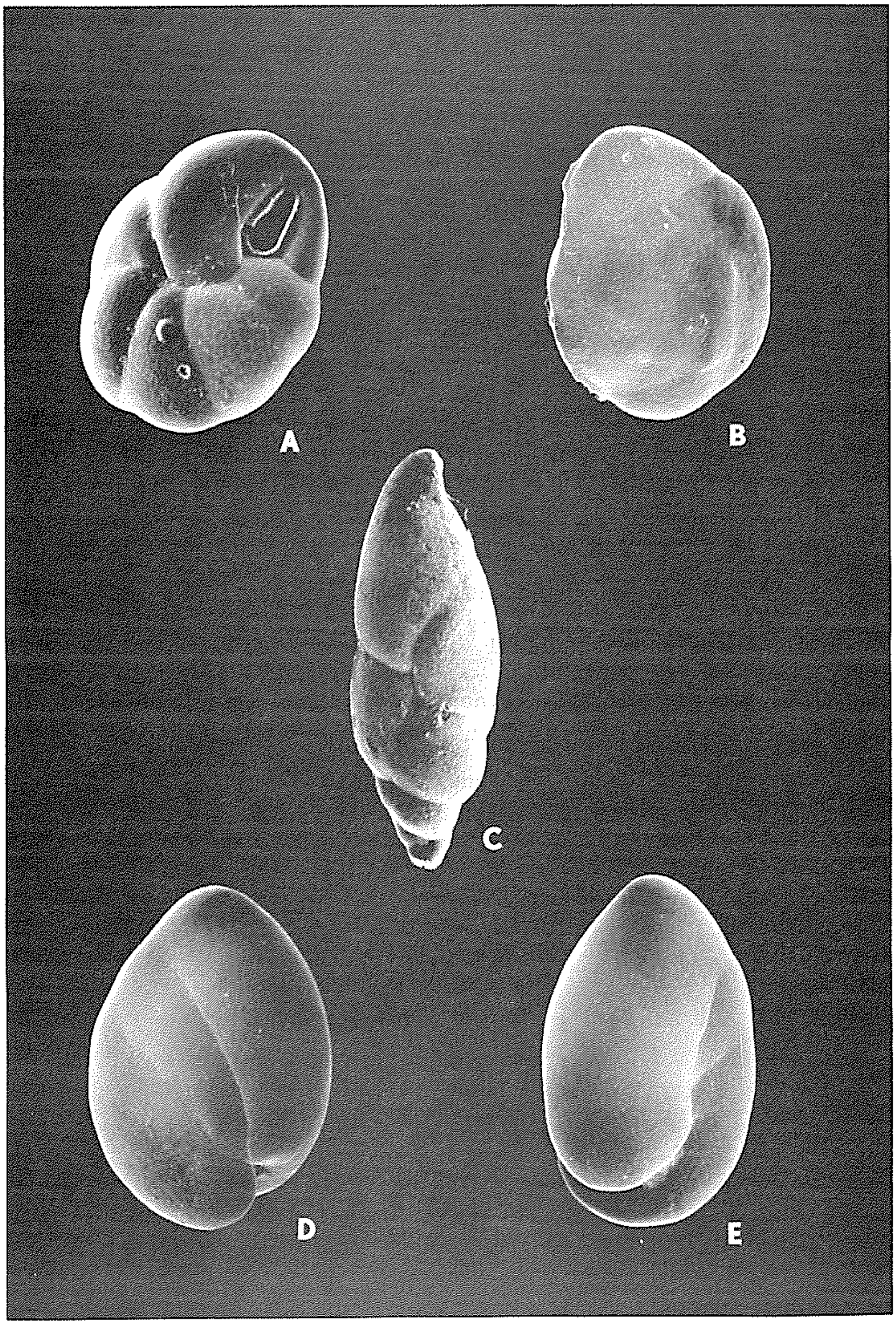

A
B
C
D
E

Plate 2

A. Elphidium cf. E. incertum (Williamson), lateral view, Core 22, 280 cm, x 250.

B. Cellanthus discoidale (d'Orbigny), lateral view, Core 37, 80 cm, x160.

C. Rosalina sp., umbilical view, Core 37, 80 cm, x240.

D. Rosalina sp., spiral view, Core 37, 80 cm, x245.

E. Ammonia beccarii (Linné), umbilical view, Core 37, 170 cm, x240.

F. Ammonia beccarii (Linné), spiral view, Core 37, 170 cm, x 180.

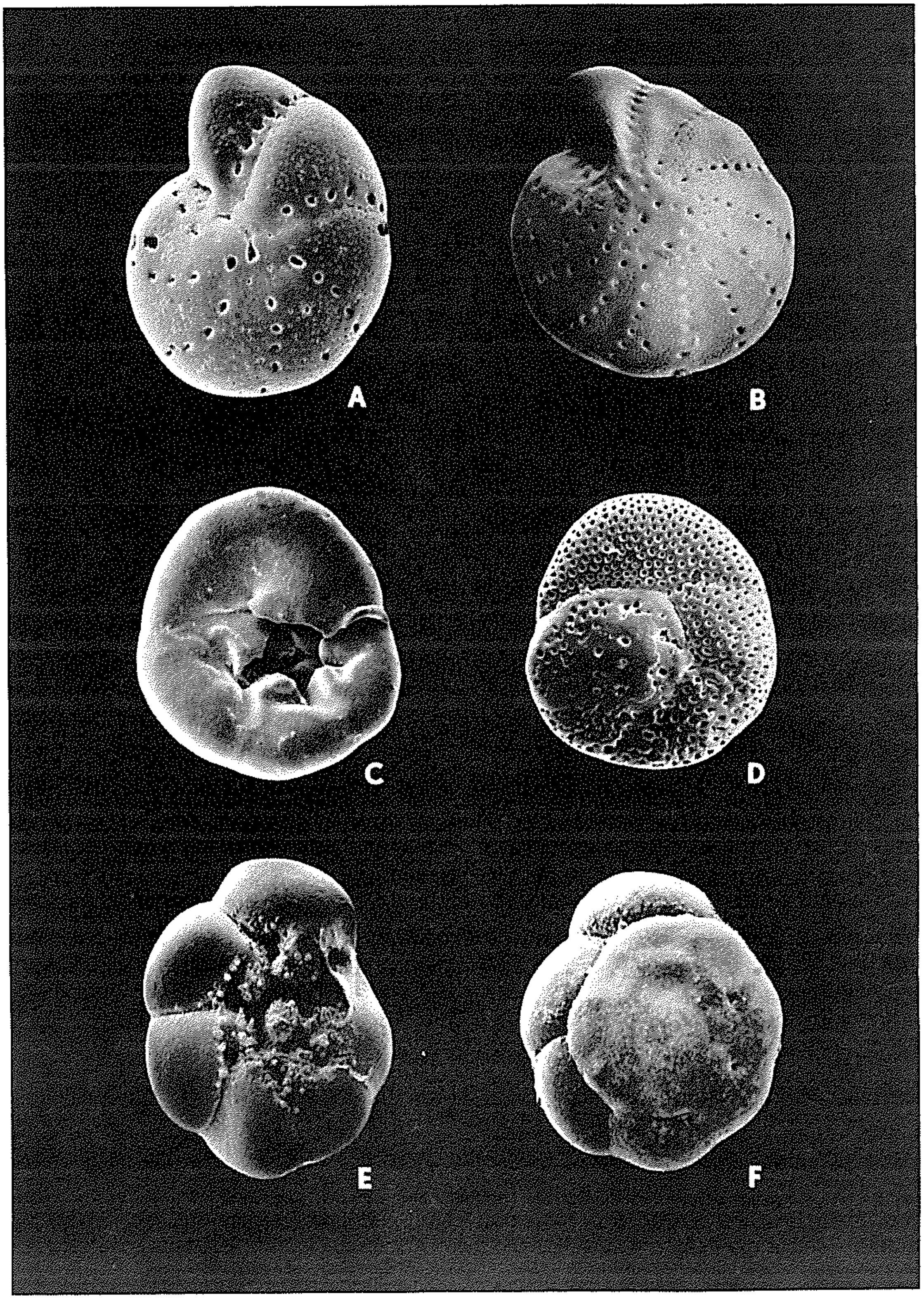

A
B
C
D
E
F

Plate 3

A. <u>Cibicidoides</u> <u>floridanus</u> (Cushman), umbonal view, Core 40, 0 cm, x 230.

B. <u>Cibicidoides</u> <u>floridanus</u> (Cushman), spiral view, Core 40, 0 cm, x 230.

C. <u>Cassidulina</u> <u>curvata</u> Phleger and Parker, sub-peripheral view, Core 27, 0 cm, x340.

D. <u>Amphistegina</u> <u>gibbosa</u> d'Orbigny, umbonal view, Core 8, 200 cm, x 70.

E. <u>Amphistegina</u> <u>gibbosa</u> d'Orbigny, spiral view, Core 8, 200 cm, x110.

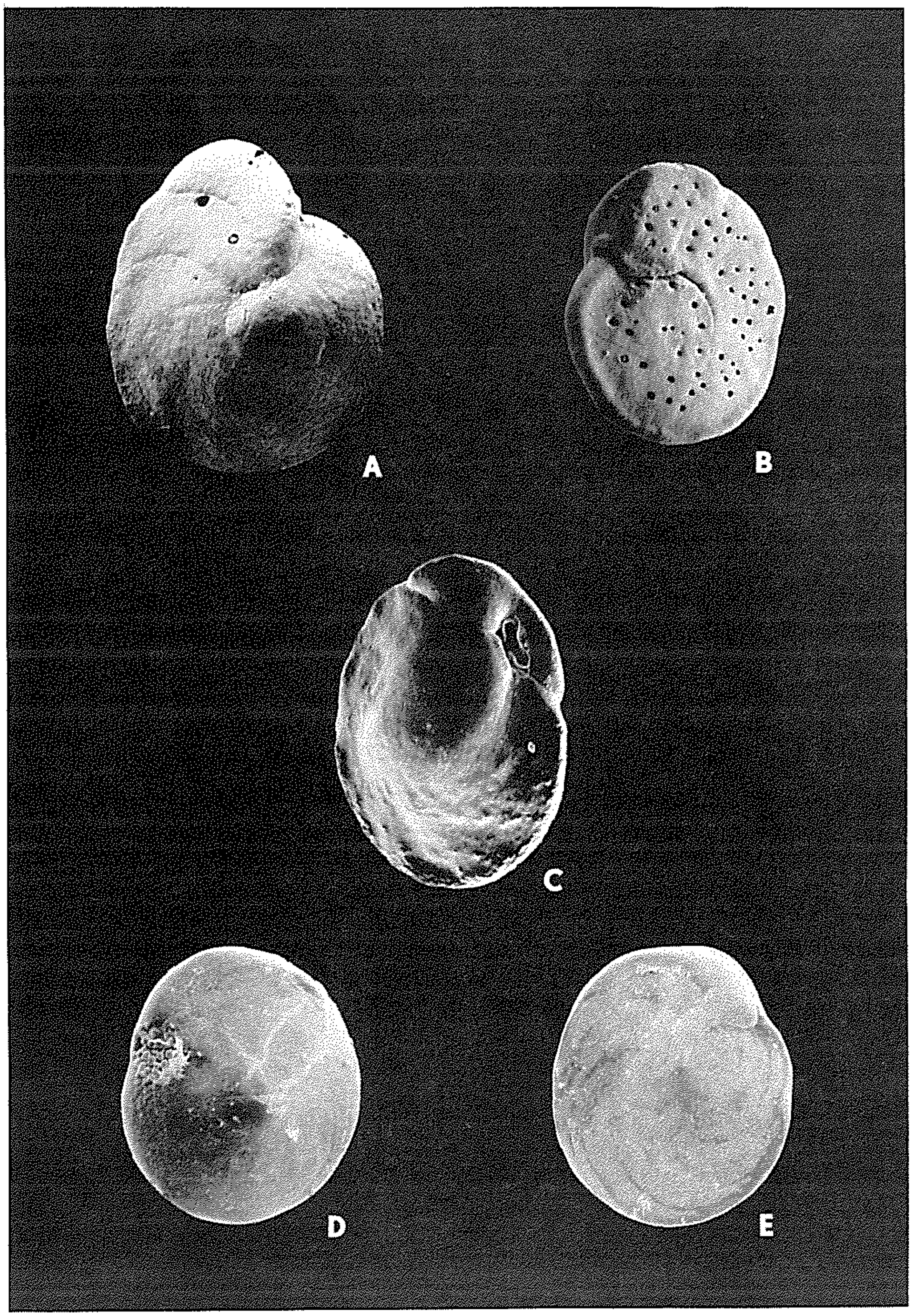

A
B
C
D
E

Plate 4

A. *Elphidium sagrum* (d'Orbigny), peripheral view, Core 42, 200 cm, x90.

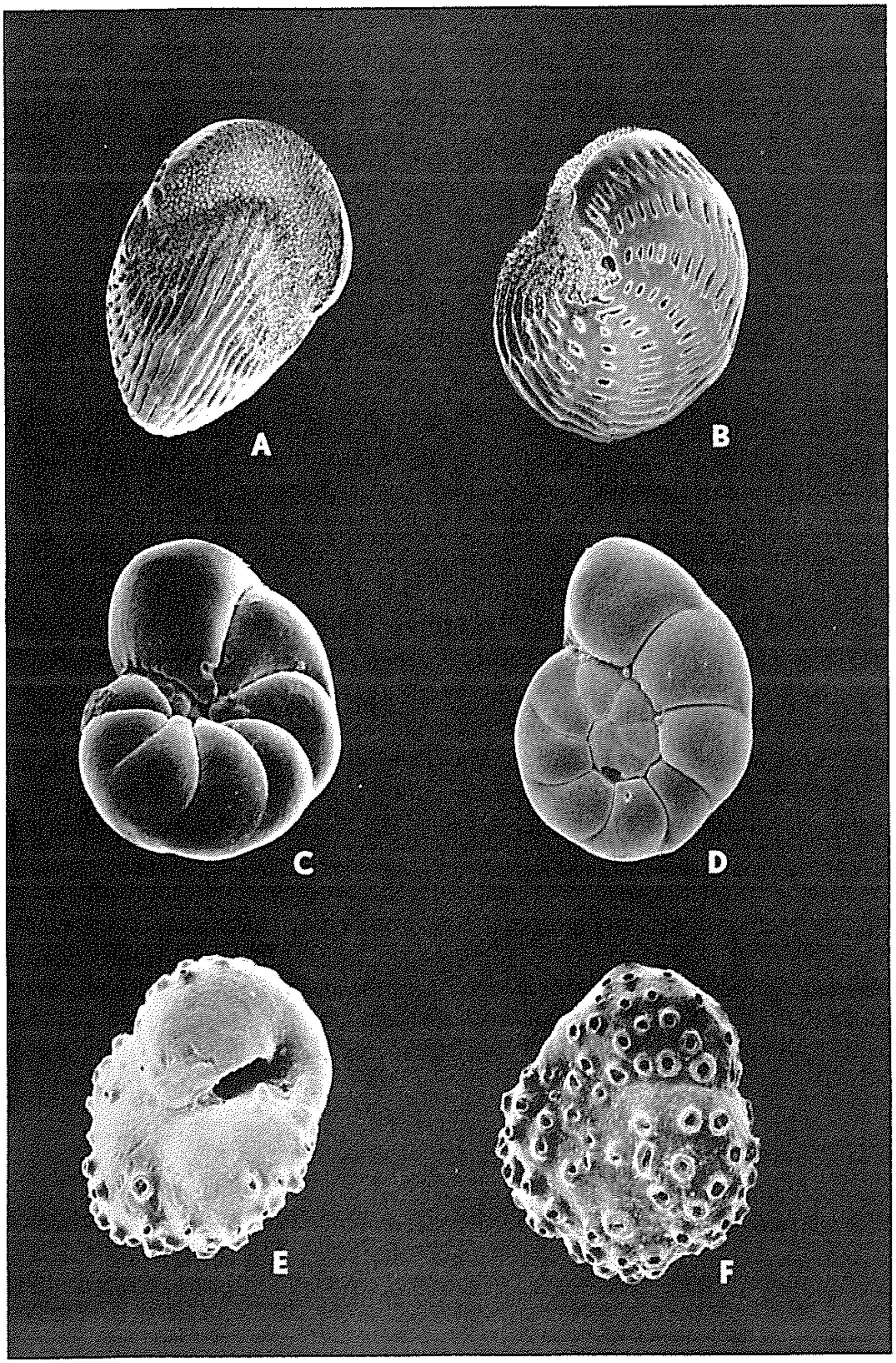
B. *Elphidium sagrum* (d'Orbigny), lateral view, Core 42, 200 cm, x100.

C. Genus X, umbilical view, Core 42, 0 cm, x370.

D. Genus X, spiral view, Core 42, 0 cm, x350.

E. Genus Y, umbilical view, Core 8, 100 cm, x360.

F. Genus Y, spiral view, Core 27, 50 cm, x360.


A
B
C
D
E
F

APPENDIX F

RADIOCARBON DATA

Sample	Sampled horizon	Material	Date (years B.P.)	Comments
TAMU 219	Core 22, 514 cm	algal nodule	28,777 ± 1461	
TAMU 220	Core 42, 143 cm	algal nodule	>30,000	
TAMU 221	Core 27, 0 cm	algal nodule	modern	
TAMU 223	Core 22, 60 cm	algal nodule	24,700 ± 1950	reworked material
TAMU 224	Core 8, 252 cm	algal nodule	26,870 ± 1,085	
TAMU 225	Core 24, 0 cm	algal nodule	1,970 ± 110	